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Aortic Stenosis

1. Classification
    a. Valvular
    b. Subvalvular
    c. Supravalvular

2. Etiologies
    a. Rhuematic
    b. Congenital
    c. Degenerative (Senile)

3. Cardinal Symptoms
    a. Angina Pectoris
    b. Syncope
    c. Congestive Heart Failure

4. Differential Diagnosis
    a. Subvalvular obstruction (membrane)
    b. Dynamic obstruction (hypertrophy)
    c. Supravalvular stenosis

5. Echo Doppler Assessment
    a. Maximal velocity/ gradient
    b. Mean gradient
    c. Valve area (continuity)
    d. Contour of the jet and LVO velocity

6. Severe Aortic Stenosis
    a. Peak AV velocity > 4.5 m/sec
    b. Mean PG > 50 mmHg
    c. AVA < 0.75 cm2
    d. LVOT/AoV TVI ratio < 0.25

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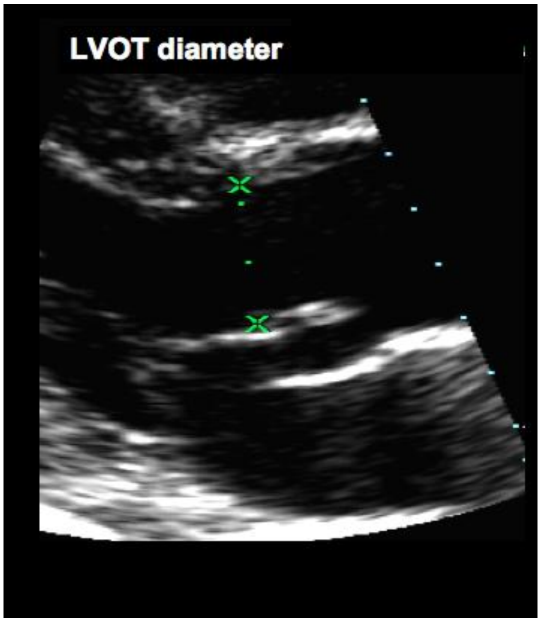
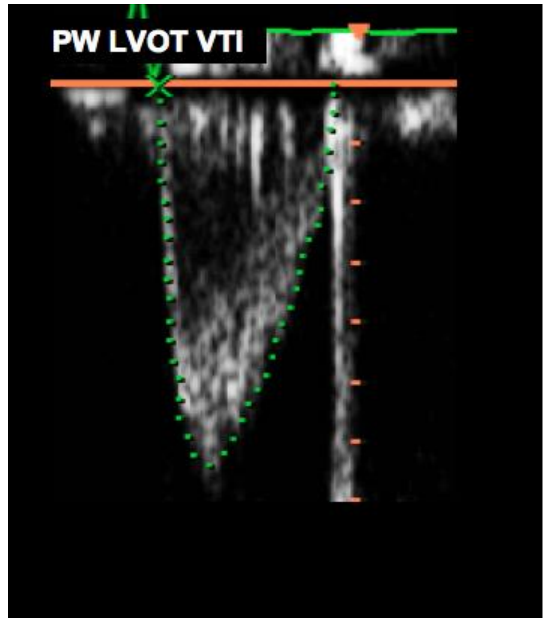
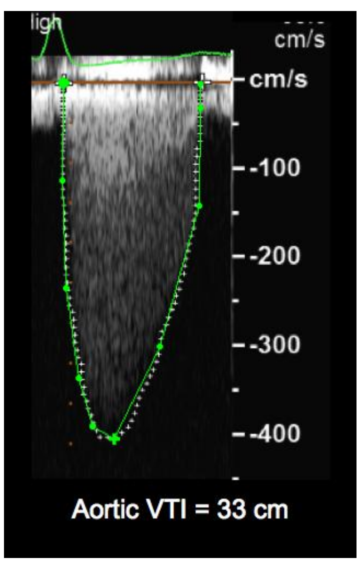




Measurement of the LVOT diameter. Measurement should be repeated three times and the largest diameter used in the calculation.

Try to place the sample volume at the same point the diameter measurement was taken. Be sure to use PW Doppler, *avoid using High PRF Doppler*



Use CW Doppler to measure the maximum velocity through the valve. Use non-imaging (Pedoff) probe from the Apex, Right Sternal Border, Subcostal and Right Parasternal windows

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Bernoulli Equation

$$P_1 - P_2 = \frac{1}{2}\rho\,(V_2^2 - V_1^2) + (\rho)\left(\int_1^2\right)(\Delta d/\Delta t)(\Delta s) + R(V)$$

Simplified Bernoulli

$$P_1 - P_2 = 4(V_2^2 - V_1^2)$$

Velocity Gradient to Pressure Gradient

$$\Delta P = 4 \times (V_2)^2$$

P_1 = pressure proximal
V_1 = velocity proximal
ρ = density (1.07g/cm^3)
Δs = path length
(V) = viscous loss

P_2 = pressure distal
V_2 = velocity distal
$\Delta v/\Delta t$ = change velocity/time
R = resistance

Errors in Doppler Derived Gradients

Overestimation

- Aortic Insufficiency
- Subaortic Membrane
- High output states
- PVC's
- Afib

Underestimation

- Poor Doppler signal
- Inappropriate angle or eccentric jet
- Proximal velocity in continuity equation
- Lack of technical expertise

- **Caveats**

- Differentiate between other systolic jets
- No LVOT diameter when extremely calcified, use non affected valve (RVOT, MV)
- LVOT obstruction can overestimate AV PG
- A-fib

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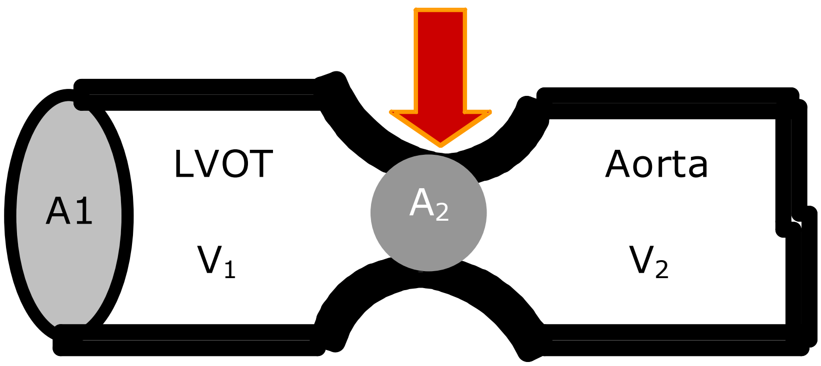
- utilize multiple cycles
- seek cycles ≤10% HR or R-R variance

Continuity Equation

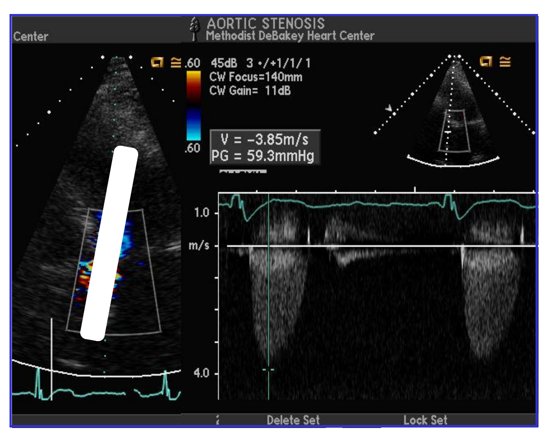


$$A_1 \times TVI_1 = A_2 \times TVI_2$$

$$A_2 = A_1 \times TVI_1 / TVI_2$$

"What comes in must go out"

<u>Alignment is Crucial</u>



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Aortic Stenosis & Dobutamine Stress Echo

Differentiating True From Pseudo – Aortic Stenosis

Indications for DSE in Patients With Aortic Stenosis

- Differentiating true from pseudo-aortic stenosis
- Measuring contractile reserve
- Predicting outcomes and management strategies

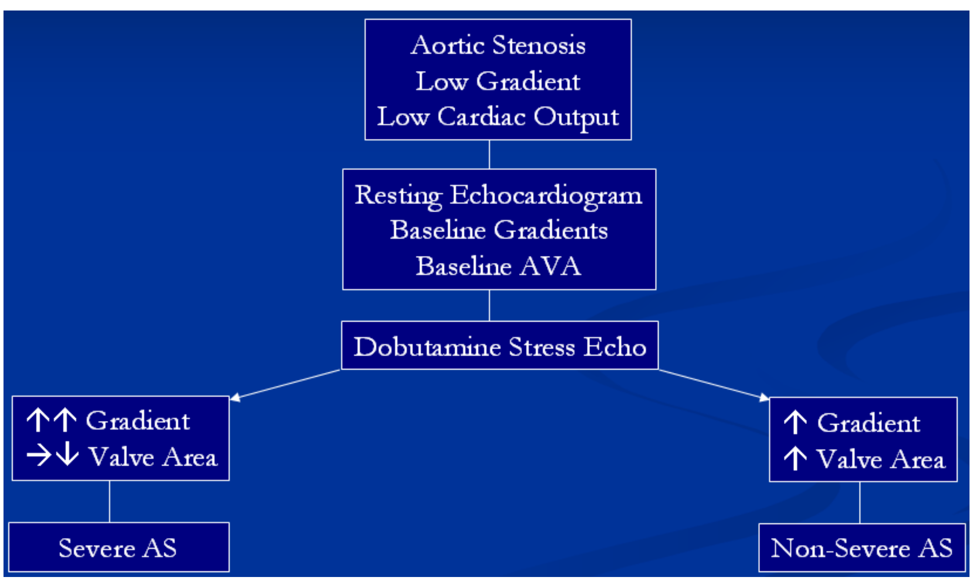
Definitions

- Pseudo-Aortic Stenosis – Decreased aortic valve area in p[patients with poor left ventricular function

- Contractile reserve – The amount myocardial function can increase in response to exercise or pharmacologic stimulation

Exam Protocol

- Normal stress test precautions
- Begin Dobutamine at 5 mcg/kg/min
- Increase by 3-5 mcg/kg/min intervals every 5 minutes



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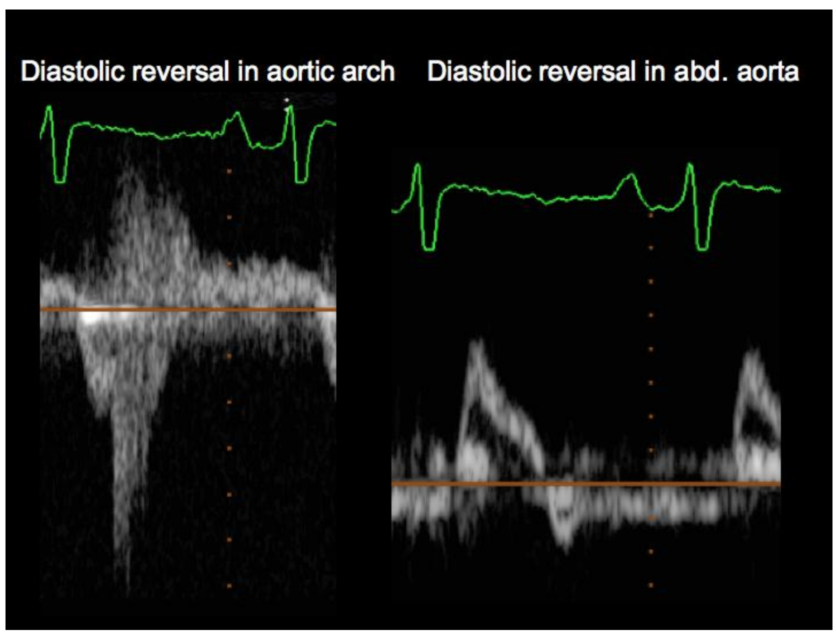
AORTIC REGURGITATION

Qualitative/Quantitative Evaluation of Aortic Regurgitation Severity
(ASE Guidelines)

PARAMETER	Mild	Moderate		Severe
Jet deceleration rate (PHT, ms)	> 500	500-200		< 200
Vena contracta width (mm)	< 3	3 -6		> 6
Jet width / LVOT diameter (%)	< 25	25-45	46-64	≥ 65
Jet CSA / LVOT area (%)	< 5	5-20	21-59	≥ 60
Regurgitant Volume (cc/beat)	< 30	30-44	45-59	≥ 60
Regurgitant fraction (%)	< 30	30-39	40-49	≥ 50
Regurgitant orifice area (cm2)	< 0.10	0.10-0.19	0.20-0.29	≥ 0.30

In addition, aortic diastolic flow reversal is a useful semi quantitative parameter. Holodiastolic flow reversal in the upper descending aorta (suprasternal notch imaging) is, generally, a sign of at least moderate aortic regurgitation. If the velocity-time integral of the flow reversal is 15 cm, it is usually associated with severe regurgitation and can be recorded as holodiastolic flow reversal in the abdominal aorta (false positive in presence of PDA or cerebral AVM).



Reduced aortic compliance with aging may prolong the normal, transient diastolic reversal in the absence of significant regurgitation.

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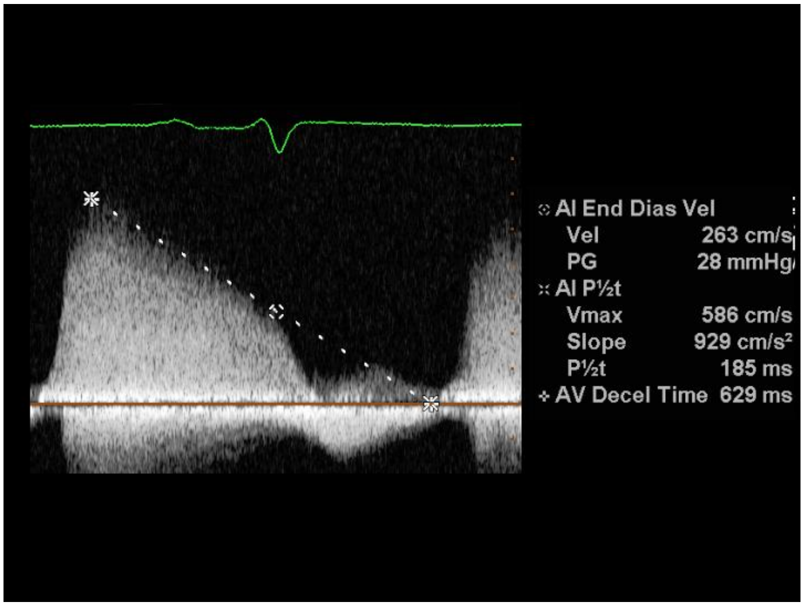
Jet Deceleration Rate



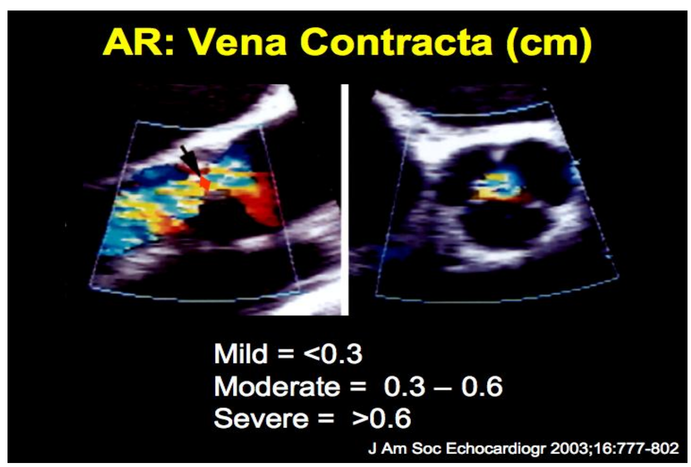
Pitfalls of PHT to assess aortic regurgitation

- Requires parallel alignment to flow
- Also affected by LV compliance
- One of the least useful parameters for semi-quantitation

Vena Contracta Width

Vena Contracta Width – The smallest neck of the flow region at the level of aortic valve

- simple measurement
- smaller than jet width in LVOT



Provides an estimate of ROA (regurgitant orifice area)

Requires visualization of all 3 components of regurgitant flow

- flow convergence region (PISA)
- vena contracta
- regurgitant jet

More robust than jet width or area

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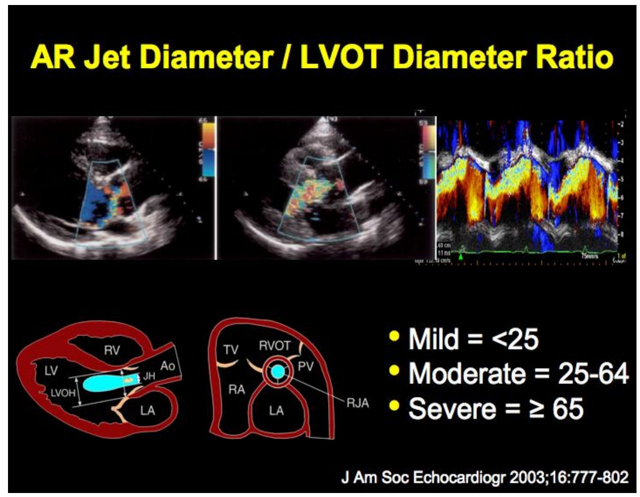
Limitations of Vena Contracta

- multiple jets
- jets with irregular shapes (i.e. one diameter not reflective of regurgitant severity); then, use short axis view.

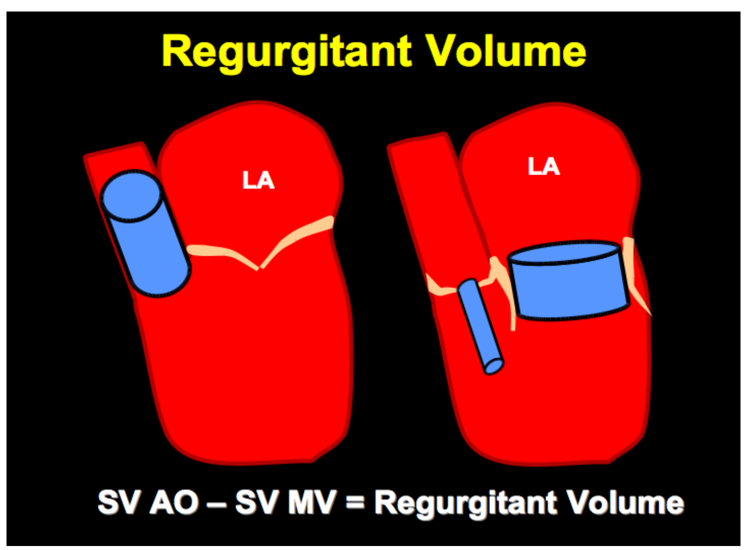
Regurgitant jet width/area

- Based on assessment of proximal jet size in LVOT(within 1 cm of valve)
- Parasternal views are preferred (i.e. better axial resolution)
- In practice, most often done as a visual estimation
- In general short axis interrogation is preferable, especially with eccentric jets



Quantitative Methods
Regurgitant Volume & Regurgitant Fraction

The continuity of flow principle states that the aortic stroke volume should equal mitral stroke volume (in the absence of regurgitant lesions). "What goes in must go out." Therefore if you calculate the Stroke Volume (SV)through the mitral valve into the ventricle and the stroke volume through the aortic valve out of the ventricle they should be very similar. Any differences in stroke volume is the result of regurgitant flow.



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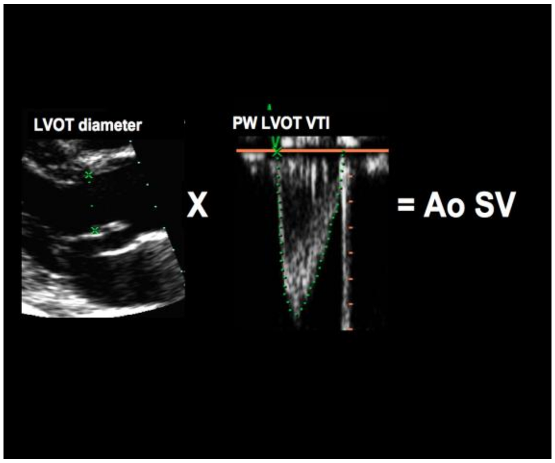
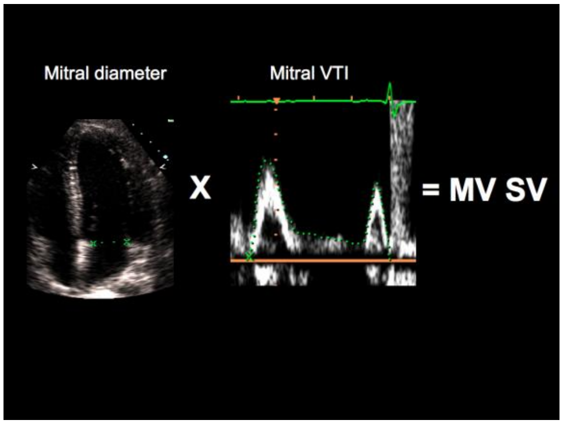


Calculate LVOT SV
Measure LVOT diameter (Parasternal long axis view)

- Obtain PW Doppler in LVOT (apical 5-chamber or apical long axis)
- Trace LVOT VTI (velocity time-integral)
- Calculate LVOT SV



Calculate MV SV

- Measure mitral annulus diameter (apical 4-chamber view or apical 4-chamber and long axis view).
- Obtain PW Doppler signal at level of mitral annulus
- Trace MV annulus VTI (trace modal velocity instead of outer envelope)

Calculating Aortic Regurgitant Volume $RV_{AV} = SV_{AV} - SV_{MV}$

Calculating Aortic Regurgitant Fraction $RF_{AV} = SV_{AV} / SV_{MV}$

Calculation of EROA (effective regurgitant orifice area)

- Using CW Doppler, obtain optimal regurgitant jet velocity (use alternate windows to achieve parallel alignment)
- Trace VTI of aortic regurgitation
- $EROA = RV_{AV} / VTI_{AV}$

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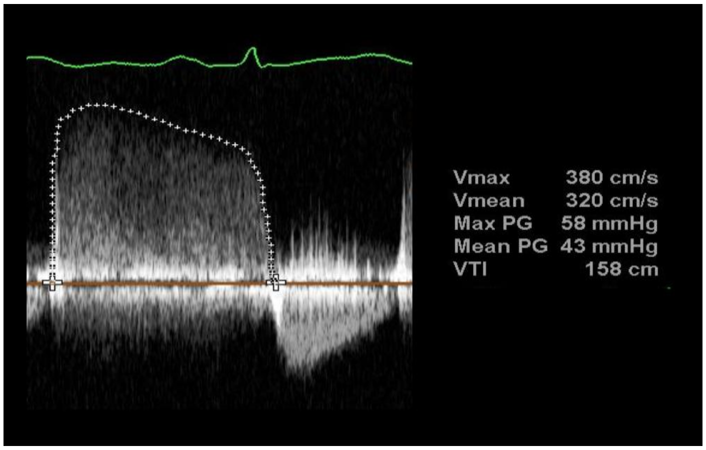

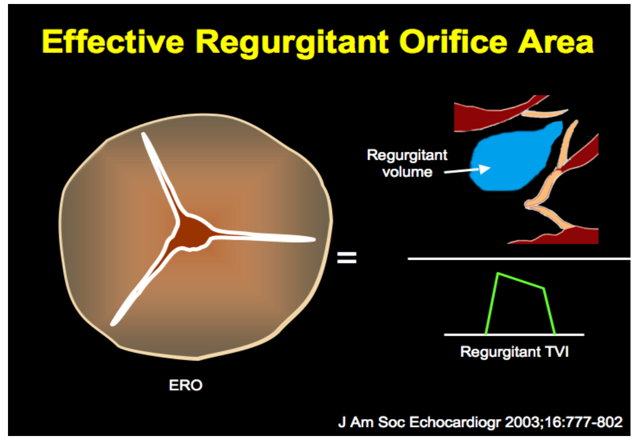

PISA METHOD

(also a continuity equation method)

- Shift color baseline in direction of flow being quantitated
- Note Alaising velocity (V_A) and timing of radius ® measurement (try to measure in early diastole

Flow (cc/sec) = 6.28 r^2 (cm)x V_A

- Using CW Doppler, obtain regurgitant jet velocity and measure peak velocity (if at time of readius measurement).

EROA (cm^2) = Flow (cc/sec) / Velocty (cm/sec)
RV (cc) = EROA (cm^2) x VTI (cm)

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Mitral Stenosis

Diagnosis :

The diagnosis of mitral stenosis is suspected on history and confirmed by

- physical examination
- electrocardiography
- echocardiography

Cardiac catheterization may aid the diagnosis and treatment in selected individuals.

Differential Diagnosis

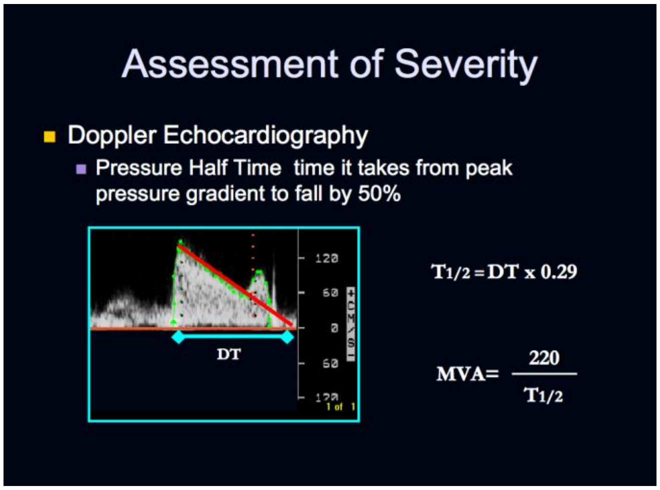
- Aortic Regurgitation
  - May give diastolic murmur and left sided failure but left ventricle is enlarged and murmur is usually parasternal and high pitched

- Chronic Obstructive Pulmonary Disease and Emphysema
  - May have cyanosis and edema, and can occur with MS, Patients with MS are frequently diagnosed as asthmatics.

- Other Problems to be Considered
  - Atrial Myxoma

Pressure ½ Time (PHT)

- The time interval for the peak pressure gradient to reach its half level.
  - Always proportionally related to deceleration time (DT)
  - DT is the time interval from peak velocity to zero baseline
  - PHT is always 29% of the DT
    - PHT = DT(.29)



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MS Severity

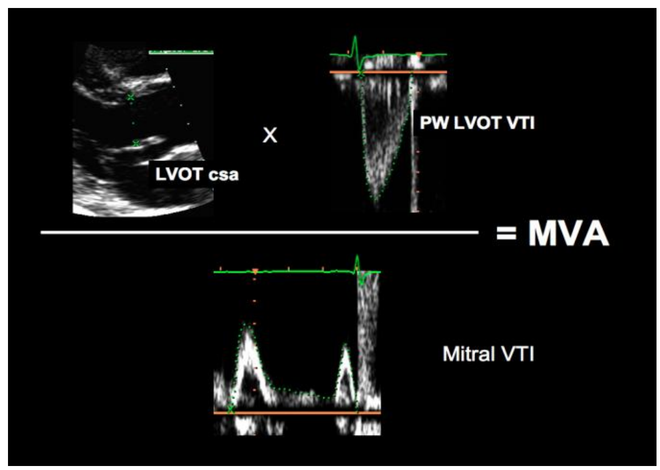
PARAMETER	Mild	Moderate	Severe
A2-OS Interval	> 110 msec	80 - 110 msec	< 80 msec
Valve Area	>1.15 cm^2	1 - 1.15 cm^2	< 1 cm^2
Gradient	< 5 mmHg	5 – 10 mmHg	> 10 mmHg

MVA: Continuity Equation

$$MVA = \frac{LVOT_{TVI} \times LVOT_{CSA}}{MV_{TVI}}$$

Caveats

- Not all prolonged PHT's = MS
- A-fib common for MS, use 5-10 cycles
- Measure longest slope
- Use PISA, continuity or planimetry if poor EF or AI (PHT will underestimate)
- MR overestimates, AR underestimates
- Low CO and HR underestimate mn PG
- Utilize Pedoff CW for eccentric jets

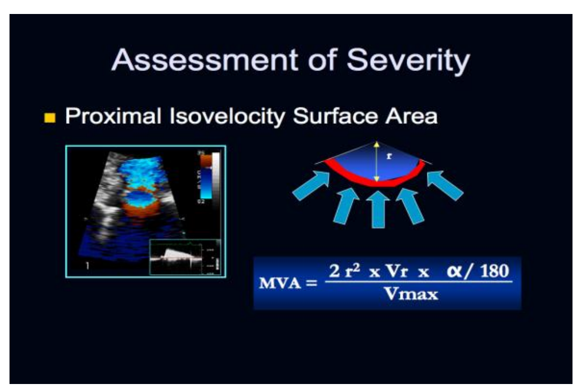


Mean Gradients

- Mean Gradient correlate with the Gorlin Formula
- Align CW cursor and trace MV inflow

PISA for Stenosis

- Adjust color scale to equal total 100 cm/sec
- Move color scale in the direction of flow
- Measure PSA radius in diastasis
- CW MV inflow
- MVA = $(2)(\pi)(r^2)(V_0/V_1)$



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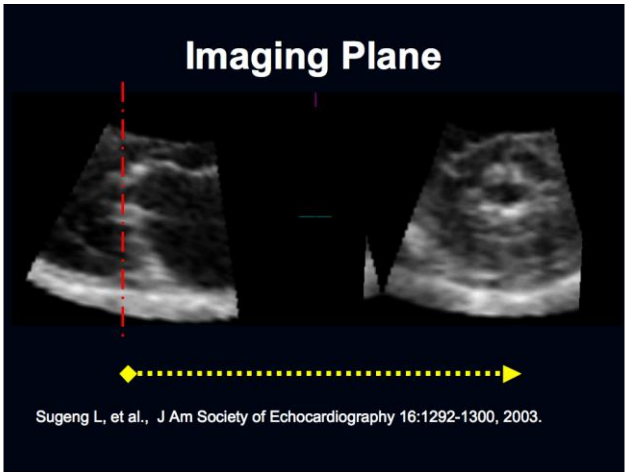
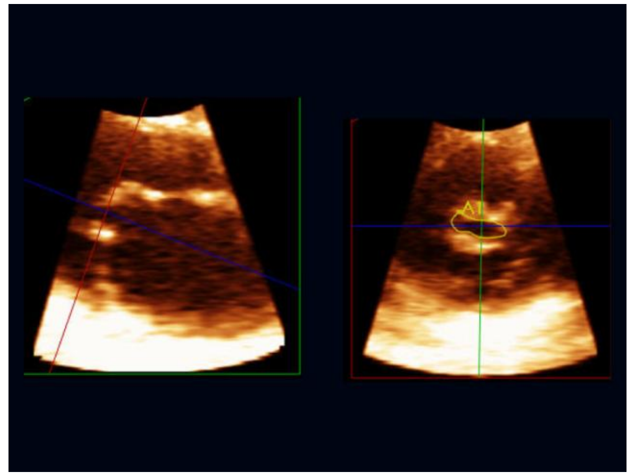
3D Assessment of MVA

- Single full volume non-gated acquisition
- Allows optimal placement of planimetry during diastasis





MITRAL REGURGITATION (MR)

Recommendations for the Evaluation of the Severity of Native Valvular Regurgitation with Two Dimensional and Doppler Echocardiography; JASE 2003; 16:777-802

Primary Regurgitation

- Regurgitation is caused an abnormality of the valve leaflets or supporting apparatus

Functional Regurgitation

- Regurgitation is secondary to some other anatomical abnormality
  - LV Dilatation
  - Papillary muscle dysfunction

Other Comments

- In addition, If MR is significant, transmitral flow velocity (E velocity) should be increased and in general
  - E-wave velocity will usually be > 1.2 m/sec in the presence of significant MR (in patients > 50 years old)
  - A large mitral valve annulus will tend to lower expectations for peak E-wave velocity even in the presence of significant MR. This finding is in the

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absence of mitral valve obstruction or other reasons for an elevated LA pressure.

- Also, pulmonary venous flows will demonstrate progressive systolic blunting with increasing levels of MR. In severe MR there may be systolic flow reversal in the pulmonary veins. The finding of systolic flow reversal in more than one pulmonary vein is a specific but not sensitive marker for sever MR. Pulmonary vein flow is influenced by LA pressure and atrial fibrillation.

Jet Area

One of the least useful measures due to a variety of technical and hemodynamic limitations. This method should not be the only method used to determine the severity of MR. This method is especially problematic in the presence of eccentric jets.

Factors that affect jet area/size

- Systemic blood pressure
- Left Atrial pressure
- Left Atrial size
- Jet direction

Vena Contracta Width

Suggestions/Pitfalls

- Whenever possible measure from PLAX using zoom views.
- Measure width of neck or narrowest portion of the jet as it emerges from the regurgitant orifice.
- Do not use apical 2-chamber view, as this view may show a wide vena contracta even in mild MR.
- Felt to be independent of flow rate and driving pressure for a fixed orifice.
- In some cases the mitral regurgitant orifice may change during systole.
- Useful for both central and eccentric jets.
- Cannot be used for multiple jets
- Use zoomed view for assessment
- Search in multiple planes
- Align jet perpendicular to the commissural line
- Regurgitant orifice is dynamic and vena contracta may change during systole

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Quantitative Methods
Regurgitant Volume & Regurgitant Fraction

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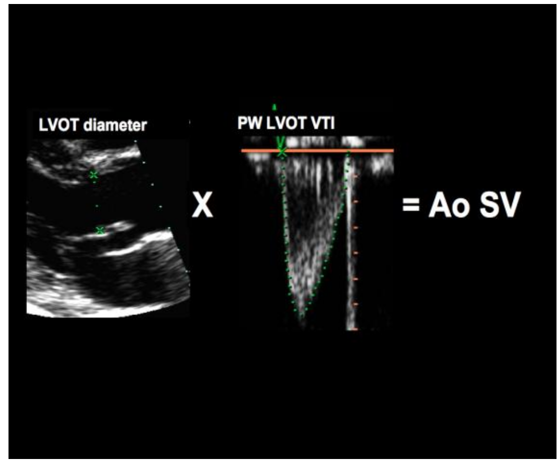

Calculate LVOT SV

Measure LVOT diameter (Parasternal long axis view)

- Obtain PW Doppler in LVOT (apical 5-chamber or apical long axis)
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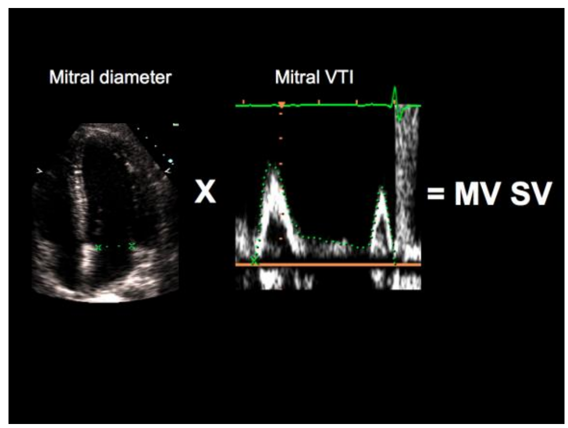
- Calculate LVOT SV



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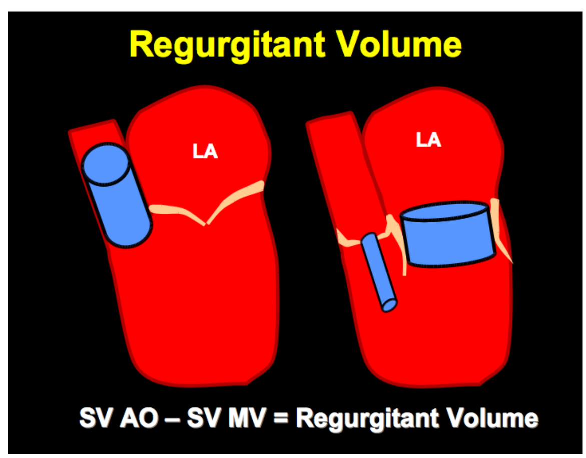
Calculating Aortic Regurgitant Volume $RV_{MV} = SV_{MV} – SV_{AV}$



Calculating Aortic Regurgitant Fraction

$RF_{MV} = SV_{MV} / SV_{AV}$

Calculation of EROA (effective regurgitant orifice area)

- Using CW Doppler, obtain optimal regurgitant jet velocity (use alternate windows to achieve parallel alignment)
- Trace VTI of aortic regurgitation

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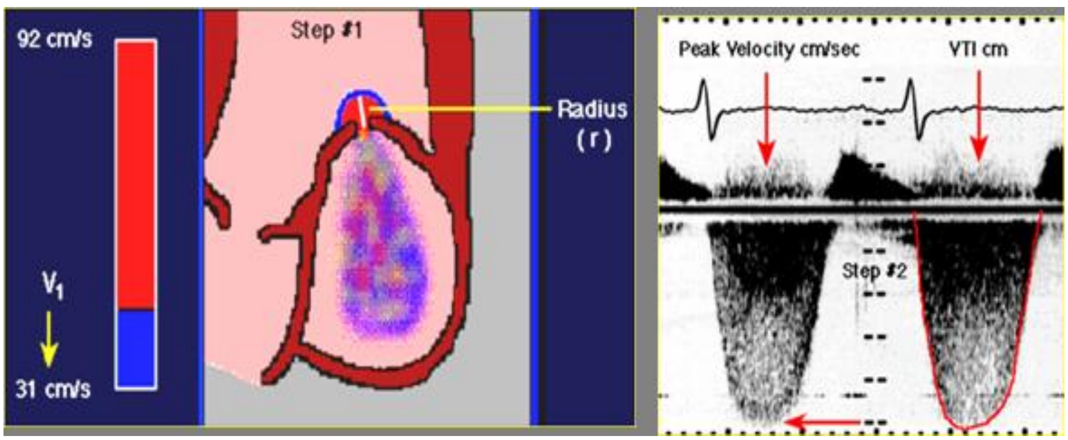
- EROA = RV_{MV} / VTI_{MV}

PISA METHOD
Also a continuity equation method

- Shift color baseline in direction of flow being quantitated
- Note aliasing velocity (Va) and timing of radius (r) measurement (try to measure at peak systole to correspond to peak regurgitant velocity) flow (cc/sec) = 6.28 x [r (cm)]^2 x Va
- Using CW Doppler, obtain optimal regurgitant jet velocity and measure peak velocity (if at time of radius measurement
- EROA (cm^2) = Flow (cc/sec) / V (cm/sec)
- RV (cc) = EROA (cm^2) x VTI (cm)



MR SUMMARY TABLE

Parameter	Mild	Moderate		Severe
Jet area (cm^2) or (%) (Nyquist limit 50-60 cm/sec)	< 4 cm^2, or <20%of LA area	Variable		> 10 cm^2 or > 40% of LA area
Vena contracta (mm)	< 3	3 – 6.9		≥ 7
Regurgitant Volume (cc)	< 30	30-44	45-59	≥ 60
Regurgitant fraction (%)	< 30	30-39	40-49	≥ 50
Regurgitant orifice area (cm^2)	< 20	0.20-0.29	0.30-0.39	≥ 0.40

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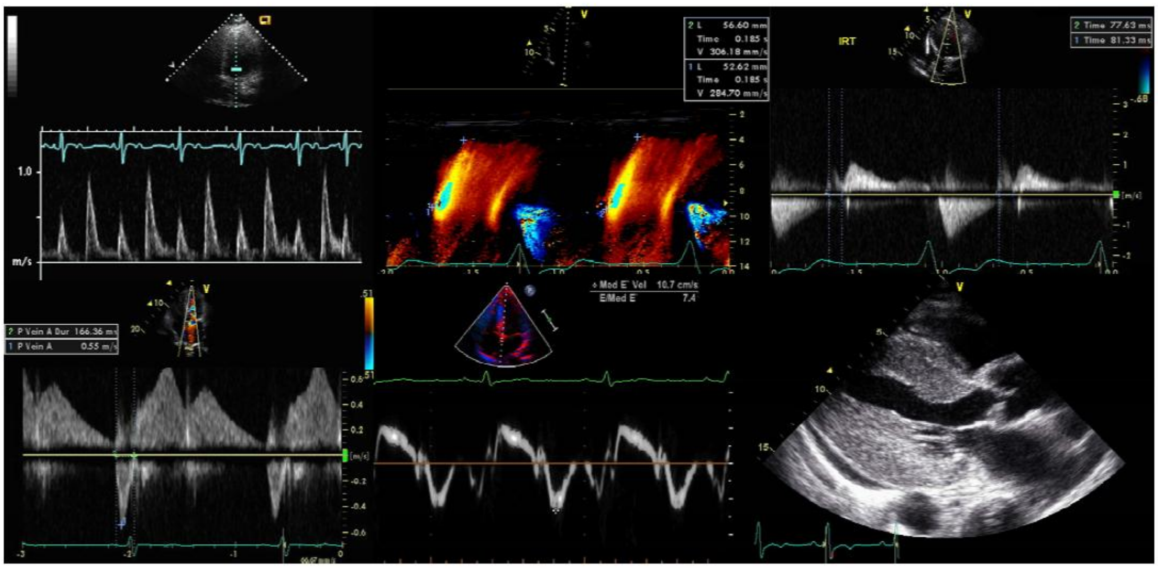
Diastolic Function for the Sonographer



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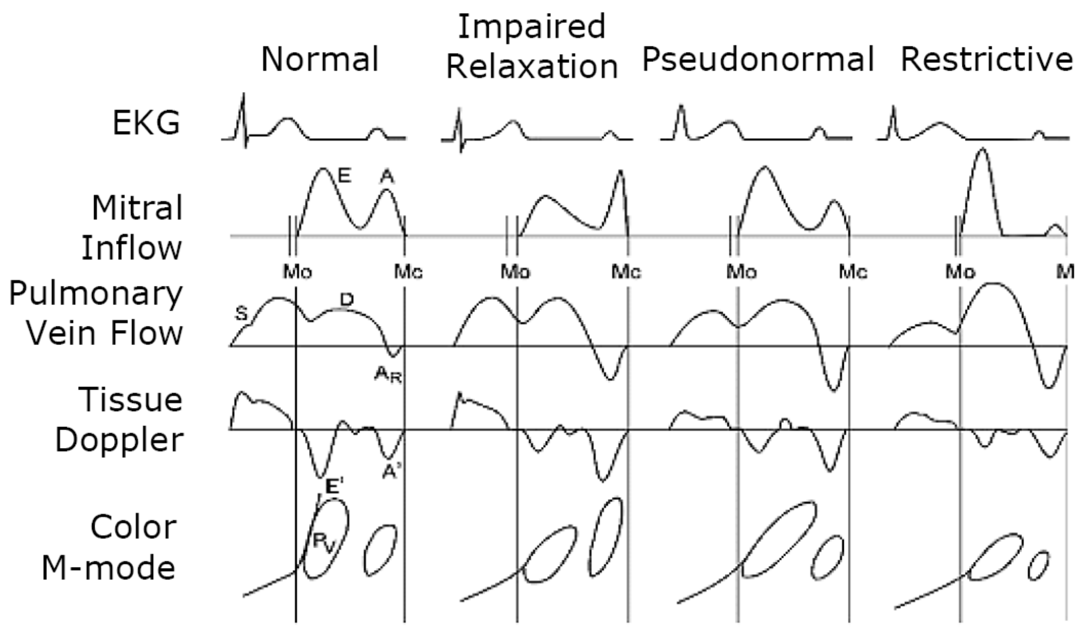
Classification of Diastolic Function



Why is Diastolic Function Important?

- **All clinical *congestive* heart failure (CHF) is essentially diastolic.**
- **May or may not coincide with systolic dysfunction.**
- **30-50% of patients with CHF have preserved LVEF (EF $\geq$ 50%).**

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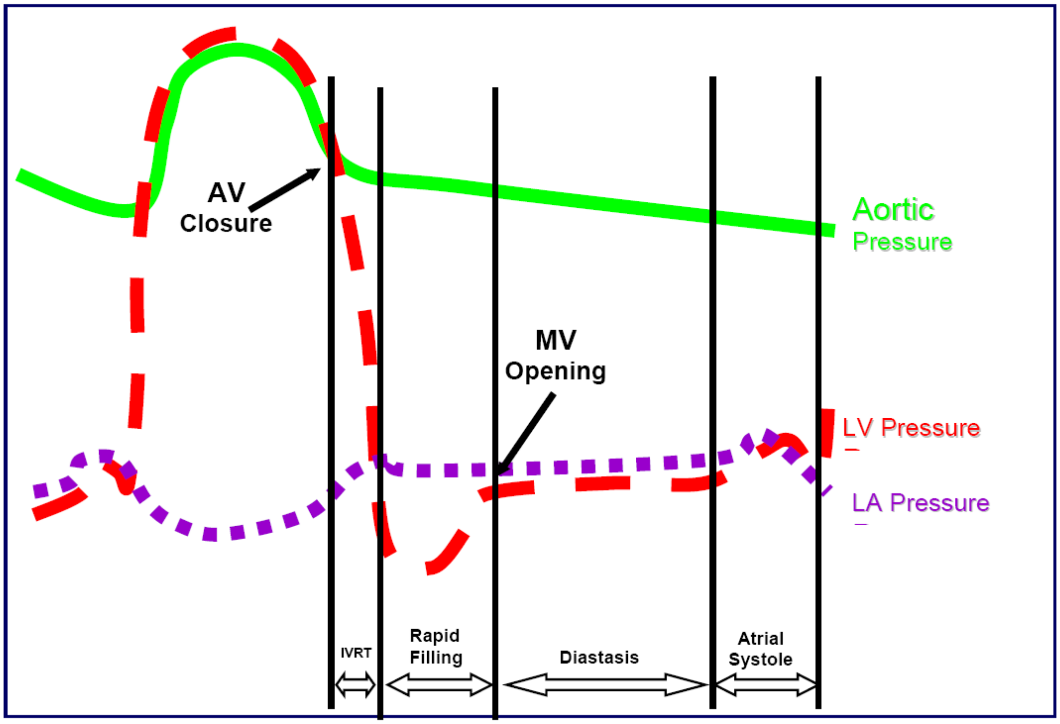
Diastolic Hemodynamics



Criteria for Diastolic Heart Failure[1]

1. **Clinical CHF (by Framingham or NHANES criteria).**
2. **Demonstration of LVEF $\geq$ 50% within 48 hours of CHF event. ***
3. **Diastolic dysfunction on cardiac catheterization or echo-Doppler.**

1. Adapted from: Zile MR, Brutsaert DL, Circulation 2002; Vasan RS, Levy D, Circulation 2000; and European Study Group on Diastolic Heart Failure, Eur Heart J 1998

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Defining Diastolic Dysfunction

- **"Diastolic dysfunction refers to a condition in which abnormalities in mechanical function are present during diastole." [2]**

- **This definition refers to left ventricular diastolic dysfunction.**

- **Therefore, it excludes abnormalities of the mitral valve, such as mitral stenosis, mitral regurgitation and prosthetic mitral valve.**

2. Zile MR, Brutsaert DL, Circulation 2002

Causes of Diastolic Dysfunction

- **Impaired Relaxation**
  - **Aging**
  - **Ischemia**
  - **Cardiomyopathy**
- **Reduced Compliance**
  - **Hypertrophy**
  - **Myocardial fibrosis**
  - **Altered Collagen Composition**
  - **Restricted Cardiomyopathy**
- **Pericardial Constriction**

Determinants of Diastolic Dysfunction

- **Gold standard: cardiac catheterization to demonstrate elevated LV filling pressures.**

- **Increasingly common modality:**
  - ***Doppler echocardiography,* since it is readily available and non-invasive.**

- **However, must be performed competently, with awareness of limitations in order to be a valid methodology.**

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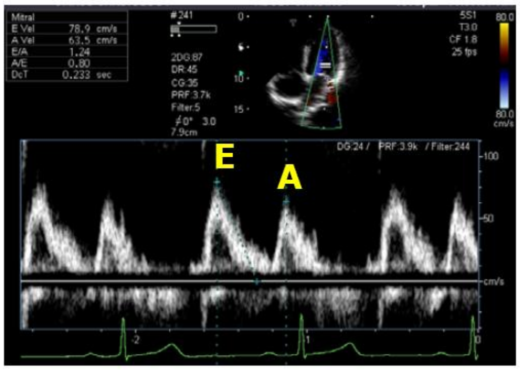
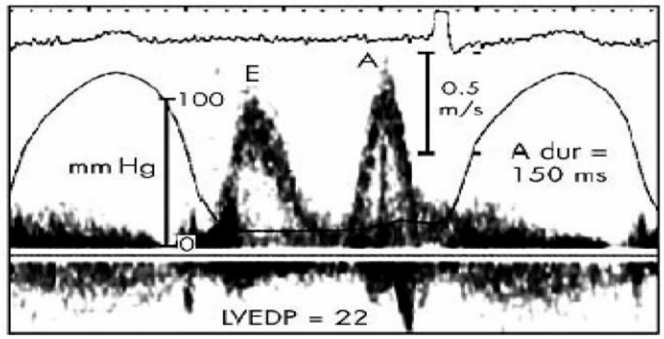
Diastology work up

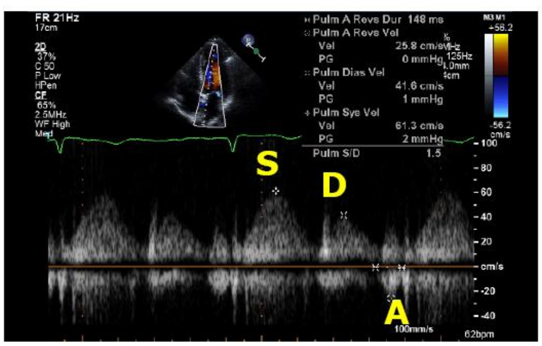
Mitral inflow

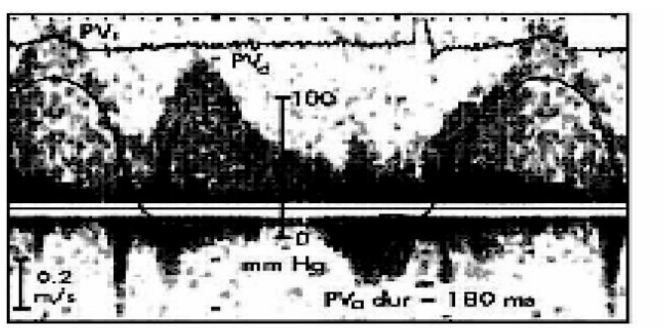




Place the SV at the leaflet tips. Measure: Peak mitral E wave, E wave deceleration time, A wave.

Pulmonary vein flow





Place the SV one cm in pulm vein. Measure: Peak S wave, D wave, A wave reversal, A wave reversal duration.

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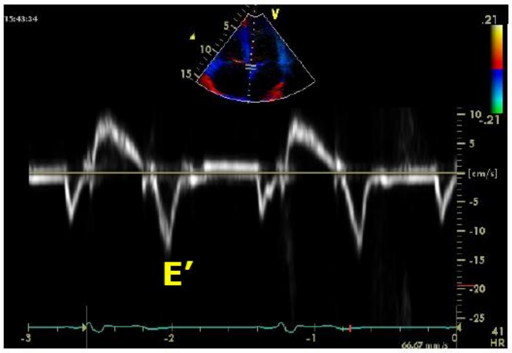
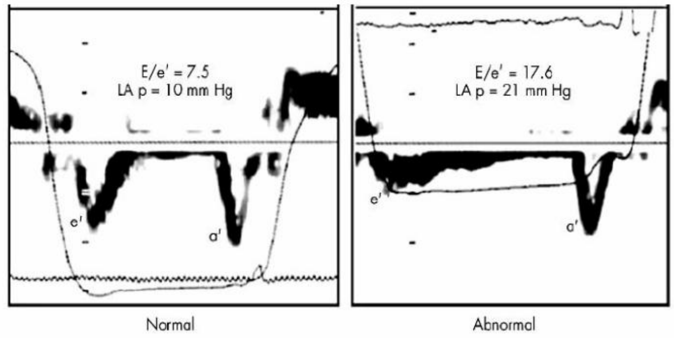
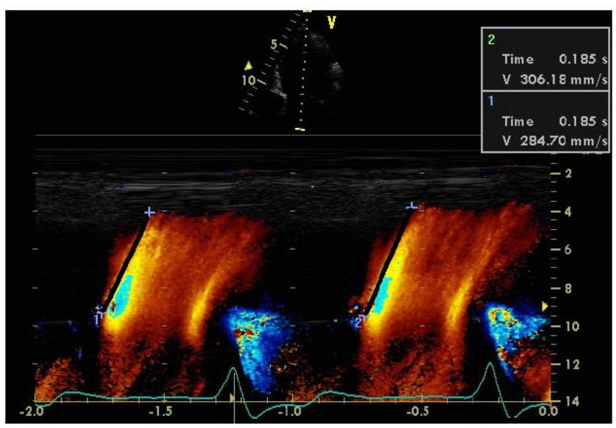
Doppler tissue imaging





Place the SV at the annulus. Measure: Peak E'; calculate the E/E' ratio to estimate filling pressures.

Color M-mode (CMM) propagation velocity



Zoom in on MV in apical views. Place color Doppler sector over LV, align the M-mode cursor as parallel as possible to inflow, shift color Doppler baseline upward. Measure: slope of early filling.

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What to look for in patients with elevated LV filling pressures

- Left atrial enlargement (without AFIB)
- Mitral E/A ratio > 1.5
- Mitral deceleration time <140 ms
- Pulmonary vein S/D < 40%
- Pulmonary vein A wave reversal velocity > 25 cm/s (elevated LV-end diastolic pressure)
- Pulmonary vein A wave reversal velocity duration > mitral A wave duration (elevated LV-end diastolic pressure)
- E/e′ ratio > 15
- Color M-mode flow propagation velocity (Vp) < 40 cm/sec

Formulas for the Estimation of LV Filling Pressures

1.9 + 1.24 (E/e′)[3]

5.27 (E/Vp) + 4.66 [4]

must be in normal sinus rhythm

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3. Nagueh SF, Middleton KJ, Kopelen HA, Zoghbi WA, Quinones MA. Doppler tissue imaging: a noninvasive technique for evalutaion of left ventricular relaxation

4. Pozzoli M, Capomolla S, Pinna G, Cobelli F, Tavazzi L. Doppler echocardiography reliably predicts pulmonary artery wedge pressure in patients with chronic heart failure with and without mitral regurgitation. J Am Coll Cardiol 1996;27:883-93.

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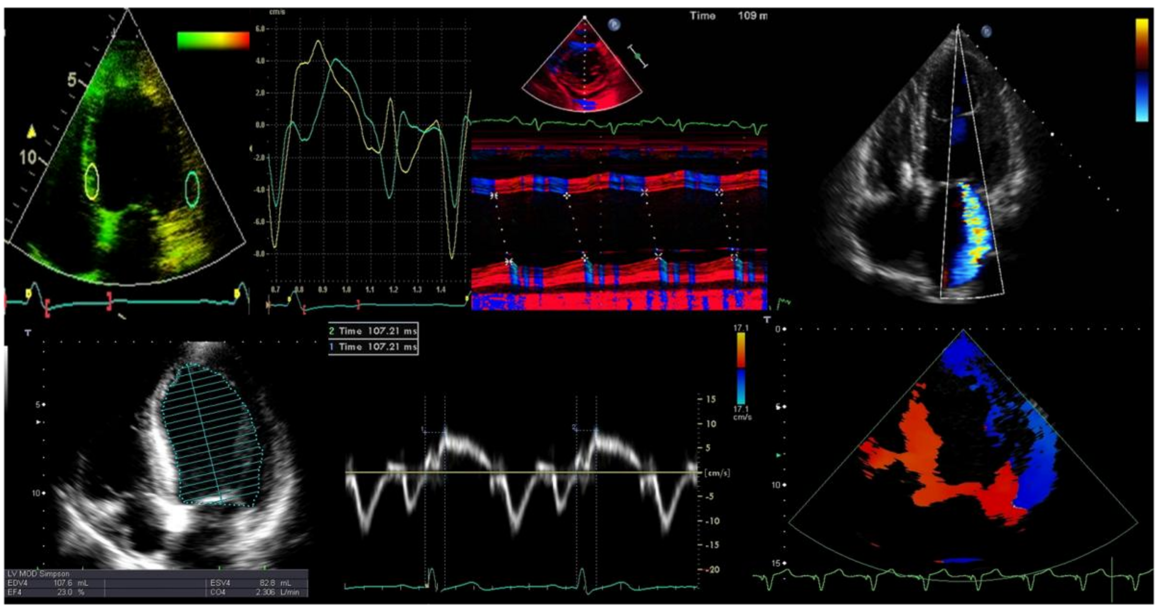
Cardiac Resynchronization Therapy (CRT)

A Comprehensive Echocardiographic Approach

Jeffrey C. Hill, BS, RDCS & Alan D. Waggoner, MHS



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Background

Heart failure (HF) and LV systolic dysfunction (LVSD)

- ~ 60% of patients have left ventricular EF < 50%.

Associated abnormalities in HF patients with LVSD

- Abnormal ventricular conduction: QRS duration > 120 ms (i.e., LBBB).
- Dilated left ventricle.
- Ventricular Dysynchrony.
- Moderate-severe aortic stenosis and/or mitral regurgitation.

Biventricular pacing/Cardiac Resynchronization Therapy (CRT)

- Biventricular pacing, or CRT, is an alternative treatment in patients with medically-refractory HF symptoms despite optimal pharmacologic therapy.

- Includes right ventricular pacing and an additional pacing catheter positioned, via the coronary sinus, to a distal coronary venous location (i.e., lateral, posterolateral, anterior) or can be surgically placed on the LV epicardium for pacing the LV.

- The goal of biventricular pacing (CRT) is to eliminate the electromechanical delay between the RV and LV to improve cardiac efficiency.

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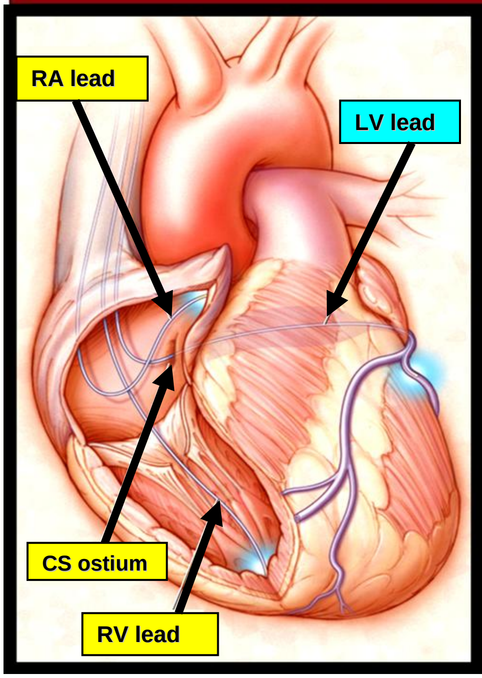
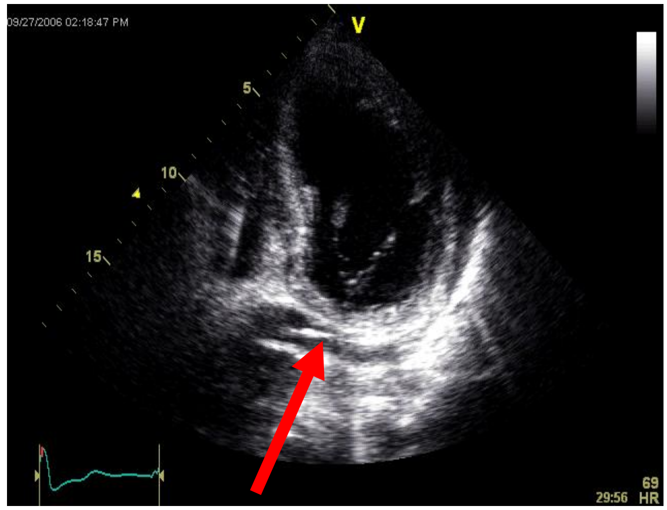


Alternative apical 4 chamber view



LV lead located in coronary sinus

RV and LV lead placement for CRT. The LV lead is inserted through the coronary sinus (CS) to the coronary venous system for LV pacing. Visualization of lead placement is seen in the coronary sinus but the actual position of the LV lead cannot be accurately determined by 2D imaging.

FDA-approved indications for Biventricular Pacing

1. Medically-refractory HF symptoms (NYHA Class III or IV) despite optimal pharmacologic therapy.
2. LV ejection fraction ≤ 35%.
3. 12 lead ECG measured QRS duration ≥120 msec.

Clinical trials* demonstrate that CRT

- Improves functional measurements of HF severity (i.e., decreases in NYHA score, improved quality of life (QoL) scores and exercise tolerance).
- Decreases LV size and improvement in LVEF.
- Decreases HF re-hospitalizations.
- Decreases HF mortality.

***** MUSTIC, NEJM 2001, PATH CHF JACC 2002, MIRACLE, NEJM 2002, MIRACLE ICD, JAMA 2003, COMPANION, NEJM 2004, CARE HF, NEJM 2005,

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Who is a "Responder" to CRT defined by echocardiography:

- Decreases in LV dimensions/volumes.
- Improvement in ejection fraction.
- Decreases in LV Dysynchrony.
- Reduction in severity of MR.
- Decreases in LV filling pressures and/or PA systolic pressures.

Who is a "Non-responder" to CRT:

- No improvement or worsening NYHA class.
- No improvement or decrease in 6 minute walk distance.
- No improvement or increase in QoL score.
- No change in LV volumes or LVEF.
- Residual mechanical Dysynchrony.
- No change in severity of MR.

Reasons for a "Non-responder" to CRT:

- Lead placement (i.e., not pacing viable myocardium).
- Discordant pacing (i.e., not pacing latest site of activation).
- Lead dislodgment.
- Co-morbidities (i.e., restrictive lung disease/right-sided heart failure).
- Not receiving optimal pharmacologic therapy.
- Programmed AV delay.
- Ischemic HF etiology.
- NYHA class IV.

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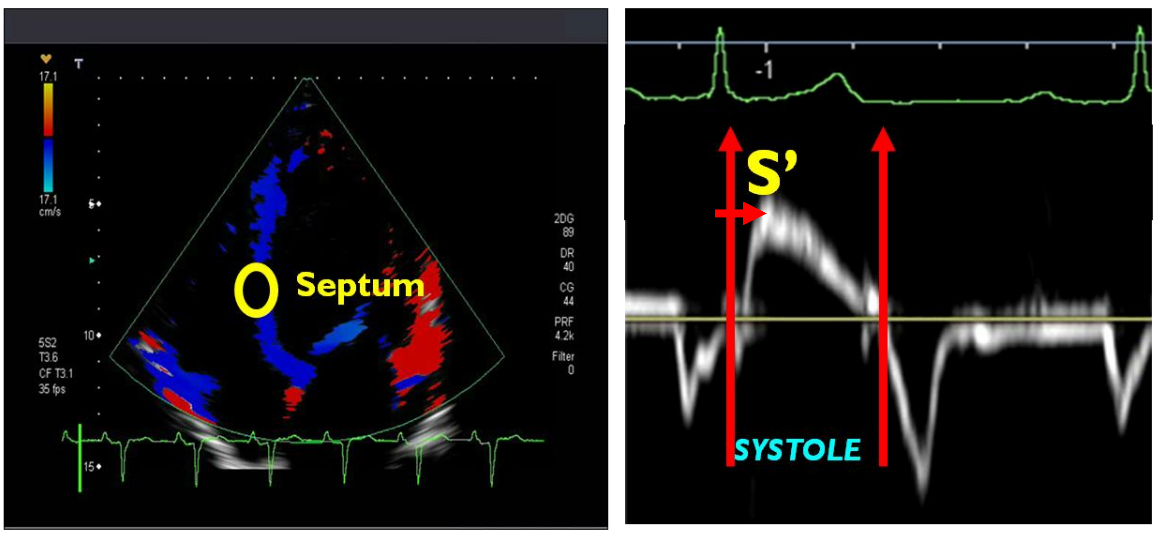
Methods for assessment of Dysynchrony by echocardiography

- Tissue Doppler Imaging (TDI)
- Pulsed wave (PW) Doppler
- M-mode echocardiography

TDI for timing and determining velocity in a myocardial segment



Color TDI is activated and a region of interest (ROI) is placed at the septal wall (circle), and to the right are the corresponding longitudinal TDI waveforms.

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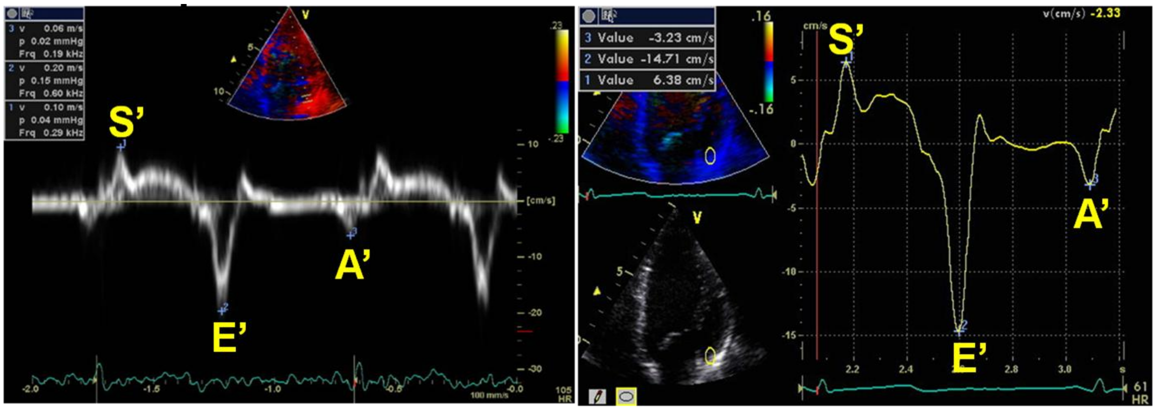
TDI: Spectral and Color Doppler

Spectral PW TDI | Color TDI



Spectral pulsed wave (PW) and color TDI obtained from the lateral annulus in the same patient. The PW TDI waveforms (left) represent the maximal instantaneous velocities. The color TDI waveforms (right) of the mean instantaneous velocities are lower. However, the time-to-peak systolic velocities are not affected, and either modality is used for the assessment of Dysynchrony.

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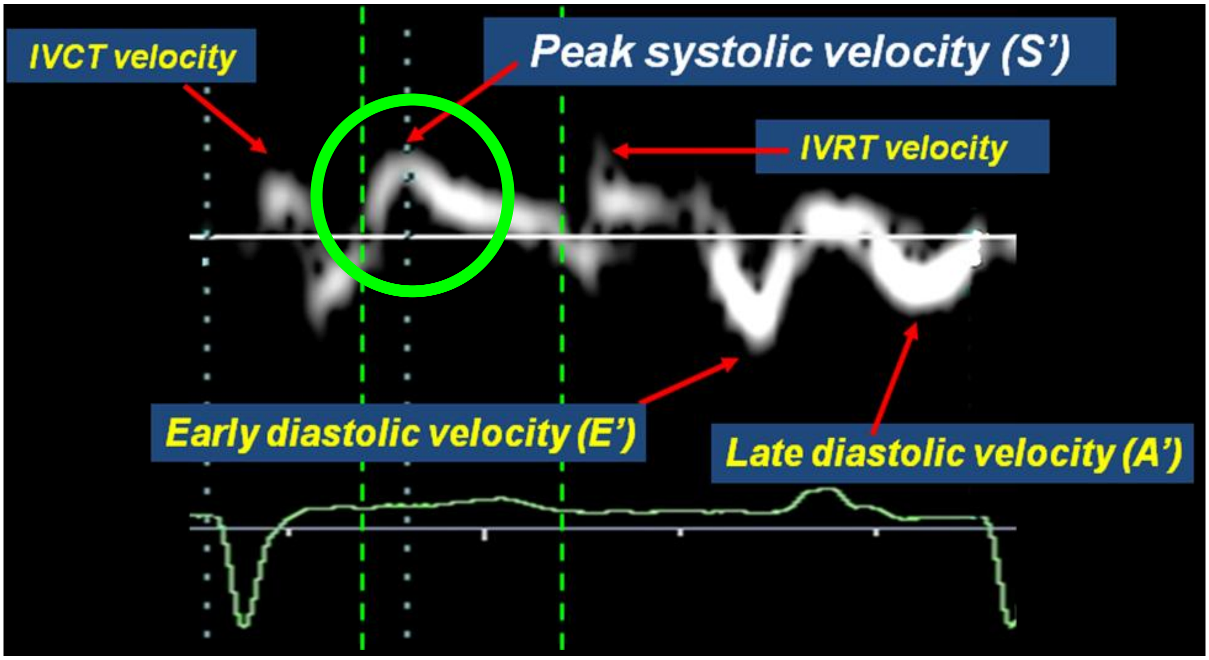
Timing of myocardial events and peak tissue Doppler waveforms



Pulsed wave (PW) spectral TDI waveform: Isovolumic contraction time (IVCT velocity) waveform occurs during the beginning of systole at the time of the QRS complex, above or below the zero Doppler baseline; isovolumic relaxation time (IVRT velocity) waveform occurs at the beginning of diastole, after aortic valve closure, and is displayed above or below the zero Doppler baseline; early diastolic velocity (E') occurs during ventricular relaxation; the late diastolic velocity (A') occurs after atrial contraction (after the P wave) at the end of diastole. The "time-to-peak" contraction of a myocardial segment is measured from the onset of the Q-wave to peak systolic velocity (S') (circled)

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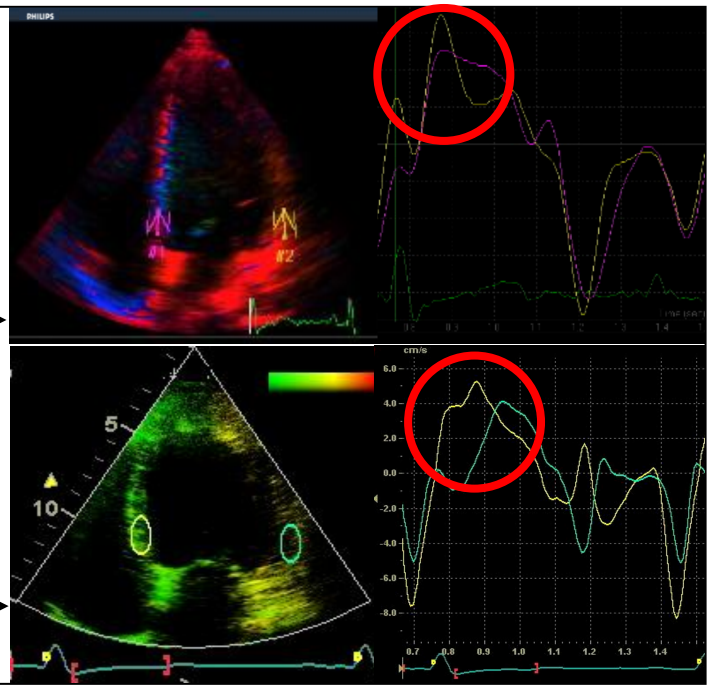
Normal vs. Dysynchrony of myocardial contraction

No significant delay in time-to-peak systolic velocities

NO Dysynchrony

Significant delay in time-to-peak systolic velocities

Dysynchrony



Top panel: color coded image and TDI waveforms display no significant delay in time-to-peak systolic TDI velocities between the septal and lateral walls (circle), no Dysynchrony. Bottom panel: color code image and the TDI waveforms indicating significant delay in timing of contraction between the septal and lateral walls (circle), consistent with significant Dysynchrony.

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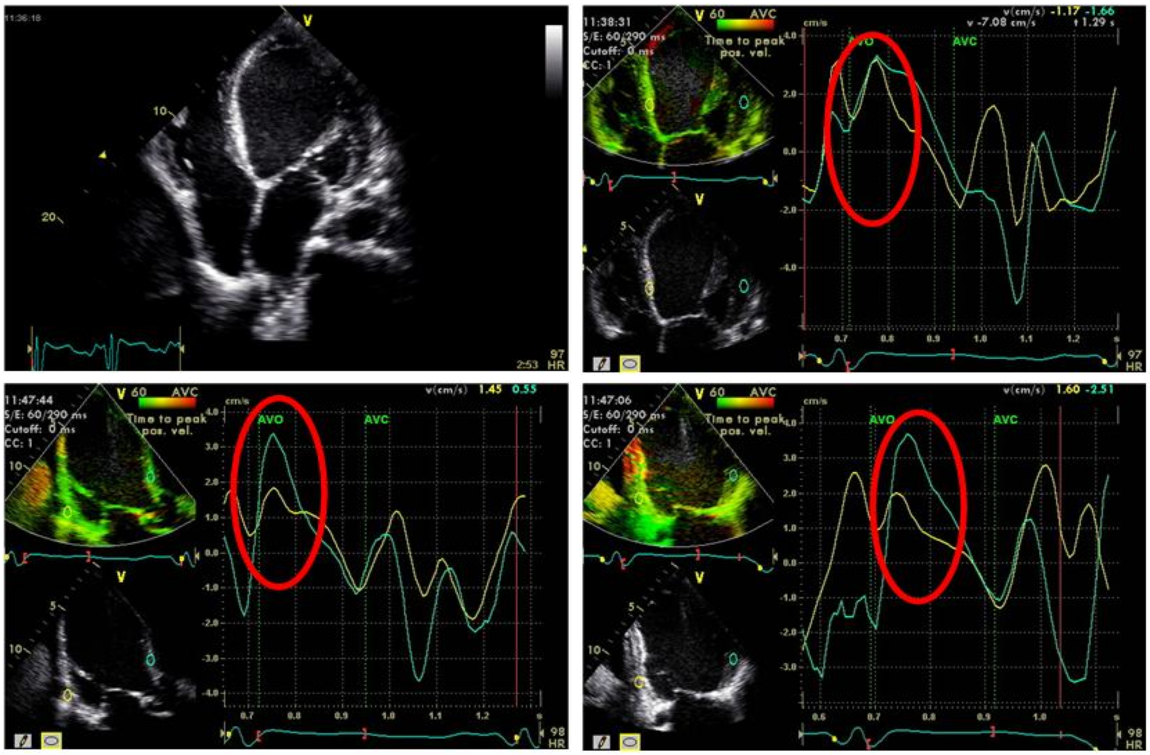
Mechanical Dysynchrony (i.e., discordant segmental LV contraction) occurs, regardless of QRS duration, in patients with CHF due to LVSD



Example of a patient with severely reduced LVEF and wide QRS interval of 162 ms. However, time to peak systolic longitudinal color TDI velocities demonstrate no significant Dysynchrony between adjacent walls in the apical 4, 3, and 2 chamber views. *

* Bleeker et al, JACC 2006;48:2243-50, Yu et al, JACC 2006;48:2251-7

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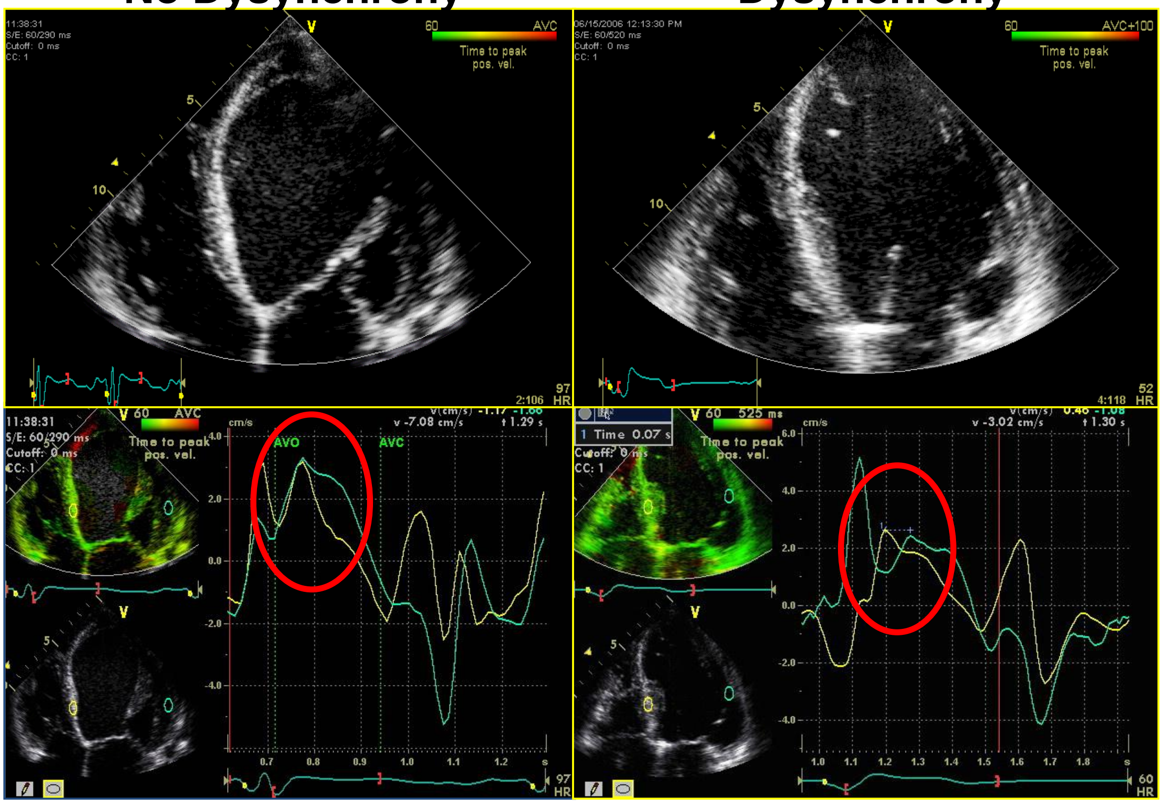
No Dysynchrony **Dysynchrony**



Top left panel is an apical 4 chamber view of a patient with an LVEF of 25%; bottom left panel is the corresponding color TDI waveforms demonstrating no significant delay in the septal and lateral time-to-peak systolic TDI velocities (circle). Top right panel is an apical 4 chamber view of another patient with a similar LVEF. There is a significant delay in the septal to lateral peak systolic TDI velocities (circle), and a delay of 70 ms indicates significant intraventricular dyssynchrony.*****

*Bax et al. J Am Coll Cardiol 2004;44:1834-40

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Two types of Dysynchrony determined by echocardiography:

- **Interventricular** Dysynchrony - significant delay between the onset of contraction between the left and right ventricle.
- **Intraventricular** Dysynchrony - significant regional mechanical delay within the left ventricle.

Interventricular Dysynchrony

1. Pulsed wave Doppler measurement of interventricular mechanical delay (IVMD)

Difference in time to opening of the pulmonary valve and aortic valve opening, defined as the time interval from Q wave to onset to valve opening, or the pre-ejection period (PEP). **IVMD ≥ 40 ms indicates interventricular Dysynchrony.** *

* Rouleau et al. Pacing Clin Electrophysiol 2001;24:1500-6

<u>Checklist for measurement of PW Doppler-IVMD</u>

Right heart acquisition

✓ Obtain the pulmonary artery view.
✓ Place the sample volume (SV) at the pulmonary valve level.
✓ Obtain PW Doppler during apnea.
✓ Adjust wall filters to clearly define valve opening on the Doppler spectral display.
✓ Measure the time interval from onset of the QRS to pulmonary valve (PV) opening.
✓ Measure 3 beats and average.

Left heart acquisition

✓ Obtain the apical 5 or 3 chamber view.
✓ Place SV at the aortic valve (AV) level.
✓ Repeat above protocol.

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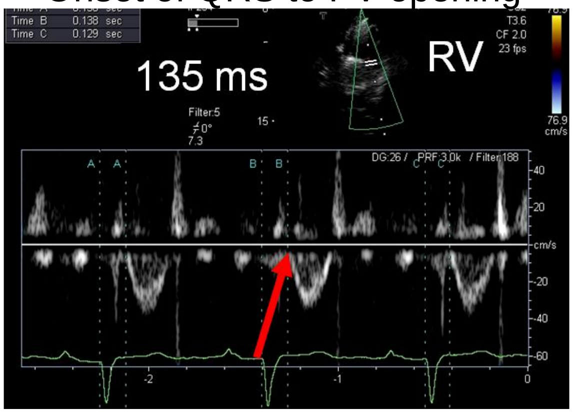
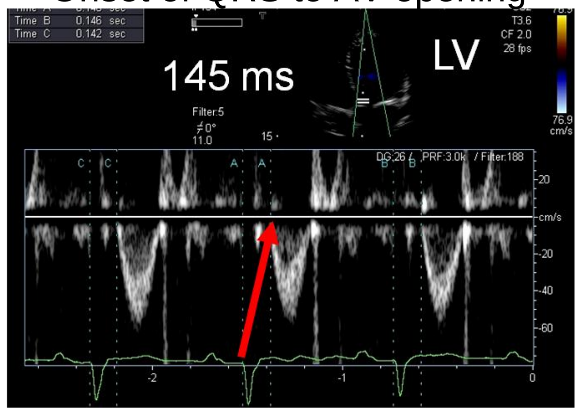
Example of IVMD and measurements

Onset of QRS to PV opening



Onset of QRS to AV opening



PW Doppler obtained at PV level from the parasternal short axis view (left). Onset of QRS to PV opening is measured and the PEP is averaged = 135 ms; PW Doppler obtained at the AV level from the apical 5 chamber view (right). Onset of QRS to AV opening is measured and the PEP is averaged = 145 ms. Time difference between the right and left PEP = IVMD.

2. Color TDI measurement of interventricular mechanical delay (IVMD)

A sample volume is placed at the RV free wall and LV lateral wall in the apical 4 chamber view. **Delay between the two segments ≥ 65 ms indicates interventricular Dysynchrony. ***

* *Bax et al. J Am Coll Cardiol 2004;44:1834-40

<u>Checklist for measurement of TDI- IVMD</u>

Right heart acquisition

- ✓ Obtain on axis apical 4 chamber view.
- ✓ Place color TDI sector over RV.
- ✓ Place the sample volume (SV) on the basal RV free wall.
- ✓ Obtain color TDI waveforms during apnea.
- ✓ Measure the onset of the QRS to peak S' velocity.
- ✓ Measure 3 beats and average.

Left heart acquisition

- ✓ Obtain the apical 4 chamber view.
- ✓ Place SV at the basal LV lateral wall.
- ✓ Repeat above protocol.

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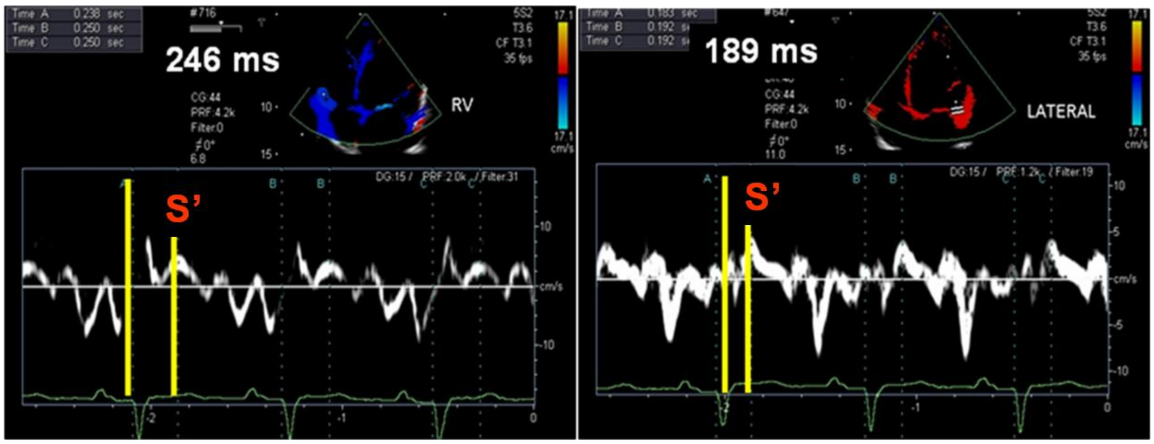
Example of Color TDI- IVMD and measurements



In the apical 4 chamber view, a region of interest is positioned in the RV and color TDI is activated (left). Onset of QRS to peak TDI systolic (S') velocity of the basal RV wall is measured; time-to-peak S' = 246 ms. Onset to peak TDI systolic (S') velocity of the LV lateral wall is measured (right); time-to-peak S' = 189 ms.

Intraventricular Dysynchrony

1. M-mode septal to posterior wall motion delay (SPWMD)

M-mode cursor is positioned by use of the 2D parasternal short axis view, to record the septal and posterior wall motion for measurement of the time delay of peak systolic displacement between the two segments. **SPWMD ≥ 130 ms indicates intraventricular dyssynchrony.***

*Pitzalis et al. J Am Coll Cardiol 2002;40:1615-22

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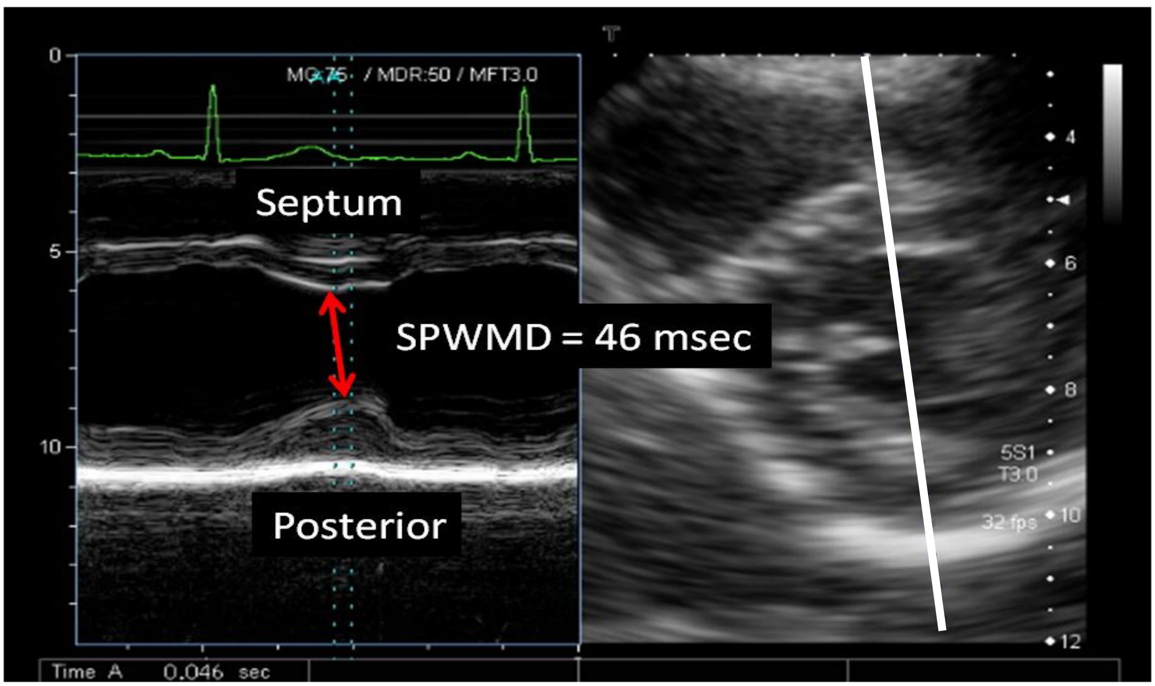
Checklist for measurement of SPWMD

Left heart acquisition

- ✓ Obtain parasternal short axis view.
- ✓ Place cursor through the LV at chordal level.
- ✓ Obtain M-mode during apnea.
- ✓ Measure (time) the peak downward displacement of the septum, and peak upward displacement of the posterior wall.
- ✓ Measure 3 beats and average.

Normal SPWMD



SPWMD measurement for intraventricular Dysynchrony with the M-mode cursor positioned through the septum and posterior wall; the SPWMD was 46 ms.

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2. TDI-derived time to peak systolic (S') velocities.

In the apical 4 & 2 chamber views, TDI time-to-peak systolic myocardial velocities are obtained in four basal LV segments. **A time difference ≥ 65 ms between LV segments indicates intraventricular dyssynchrony.***

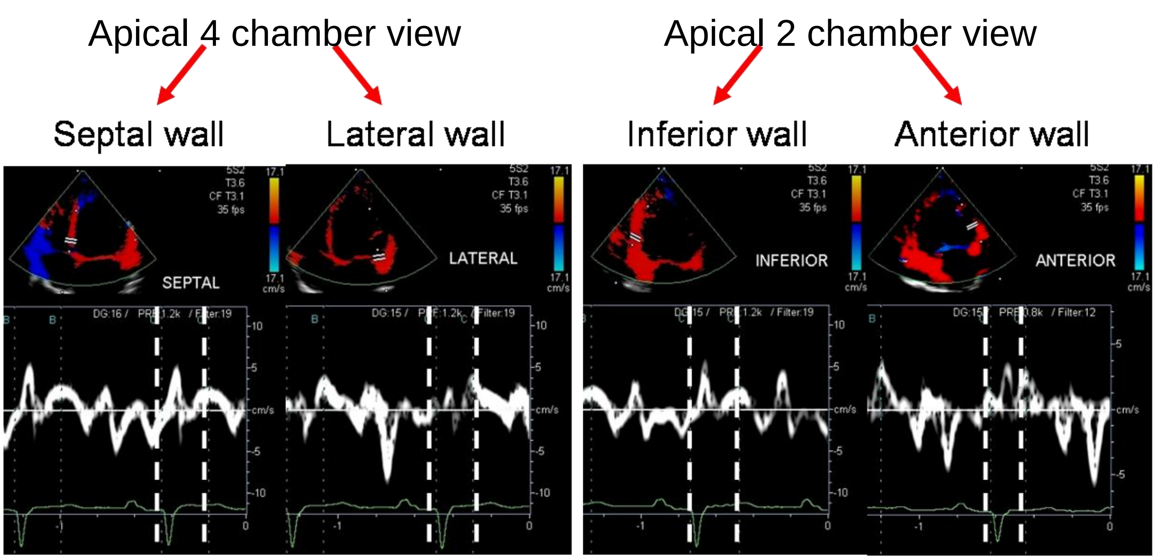
*Bax et al. J Am Coll Cardiol 2004;44:1834-40

Checklist for measurements of TDI time-to-peak S' velocities

Left heart acquisition

- ✓ Obtain apical 4 chamber and 2 chamber views.
- ✓ Place color TDI sector over the LV in each view.
- ✓ Place SV at the LV base, adjacent to the mitral annulus.
- ✓ Obtain color TDI waveforms during apnea.
- ✓ Do not measure IVCT velocities during QRS because they do not represent active myocardial contraction.
- ✓ Clearly define peak systolic contraction (S') velocities.
- ✓ Measure time-to-peak S' velocities.
- ✓ Measure 3 beats and average.

Example of TDI and measurements



In the apical 4 and 2 chamber views, a region of interest is drawn over the LV and color TDI is activated. Onset of QRS to peak TDI systolic (S') velocity of the basal septal, lateral, inferior, and anterior walls are measured.

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3. TDI-derived time to peak systolic (S') velocities obtained at the base and mid LV in the apical 2, 3, 4 chamber views

The technique can be extended to measurements in 12 LV segments and the standard deviation (SD) of the time to peak velocities, or Dysynchrony index (Ts-SD) is calculated. **A Ts-SD ≥ 33 ms indicates intraventricular dyssynchrony.***

*Yu et al. Am J Cardiol 2002;91:684

TDI sample site	TDI measurements			Average
	1	2	3	
Ts- mid septal (ms):	160	160	160	160.00
Ts- basal septal (ms):	180	170	180	176.67
Ts- mid lateral (ms):	240	240	240	240.00
Ts- basal lateral (ms):	230	230	250	236.67
Ts- mid anteroseptal (ms):	140	140	140	140.00
Ts- basal anteroseptal (ms):	160	150	150	153.33
Ts- mid posterior (ms):	230	230	230	230.00
Ts- basal posterior (ms):	240	240	240	240.00
Ts- mid anterior (ms):	150	150	160	153.33
Ts- basal anterior (ms):	160	160	160	160.00
Ts- mid inferior (ms):	210	222	240	224.00
Ts- basal inferior (ms):	250	260	220	243.33
Ts-SD				**42.00**

Example of time-to-peak TDI velocities at basal- and mid-ventricular levels obtained in the apical 4, 3, and 2 chamber views including the average and standard deviation (Ts-SD).

AV Delay optimization and CRT

Background

What is the atrioventricular (AV) delay?

- The time delay between electrical activation of the atria and the ventricles (i.e., electrocardiographic PR interval)

Why is AV delay optimization important for CRT?

- Improved AV synchrony.
- Maximize preload recruitment and LV filling.
- Increase the rate of LV pressure development (dP/dt).
- Increase LV stroke volume and cardiac output.
- Eliminate diastolic MR (if present.)

What is the optimal AV delay?

- The programmed AV delay that optimizes ventricular filling.
- The programmed AV delay that increases stroke volume.

Methods to determine the AV delay after CRT

- Program the AVD to 100 -120 ms.
- Program the AVD by the PR interval x 0.5.
- Program the AVD to ↑ LV diastolic filling (i.e., Ritter, "Iterative", or VTI methods).
- Program the AVD to ↑ +LV dP/dt (i.e., CW MR jet acceleration).
- Program the AVD to ↑ aortic VTI (i.e., SV).
- Optimal AVD varies from 80 – 200 ms.

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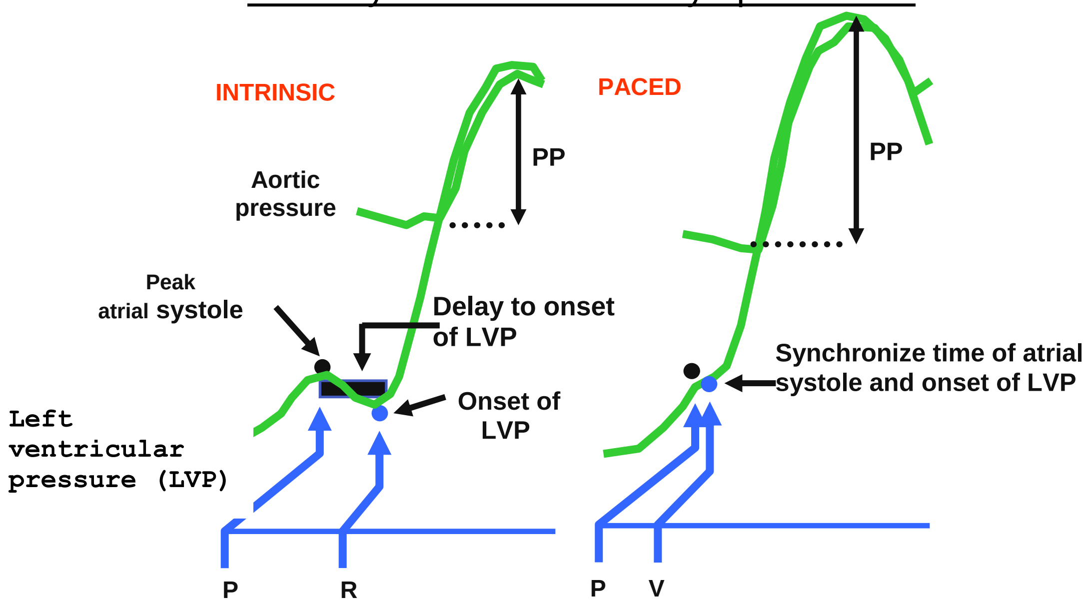
AV delay optimization: Doppler measurements of LV diastolic filling

- Ritter method
- “Iterative” (separation of mitral E and A wave velocities)
- Mitral velocity time integral (VTI)

Hemodynamics of AV delay optimization



Goal: improve AV synchrony, “recruit preload”, ↑ LV (+) dP/dt, pulse pressure (PP), and stroke volume

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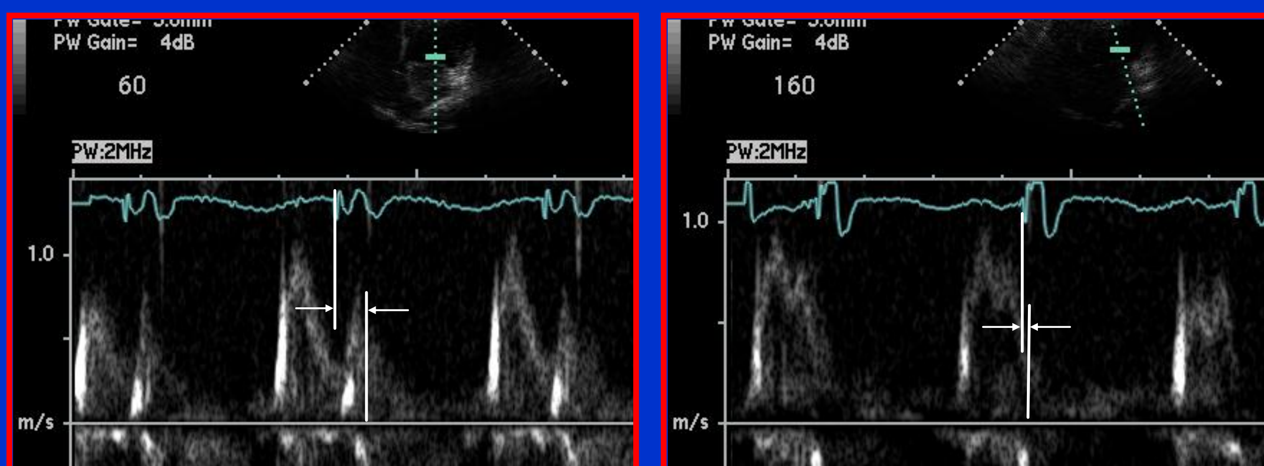
Mitral inflow: Ritter method

Mitral inflow (Ritter method)

AV delay: 60 ms | **AV delay: 160 ms**



Pace-MV closure = 100 ms | **Pace-MV closure = 20 ms**

(100 - 20 = 80)
Long AV delay (160) - 80 = 80 (optimal AVD)

- ✓ Program the CRT device to a short AVD (wait at least 10 cardiac cycles) and measure the time interval from pacing spike to closure of the mitral valve.
- ✓ Program the CRT device to a long AVD (wait at least 10 cardiac cycles) and measure the time interval from pacing spike to closure of the mitral valve.
- ✓ Difference in the measured time intervals are subtracted from the longest programmed AVD

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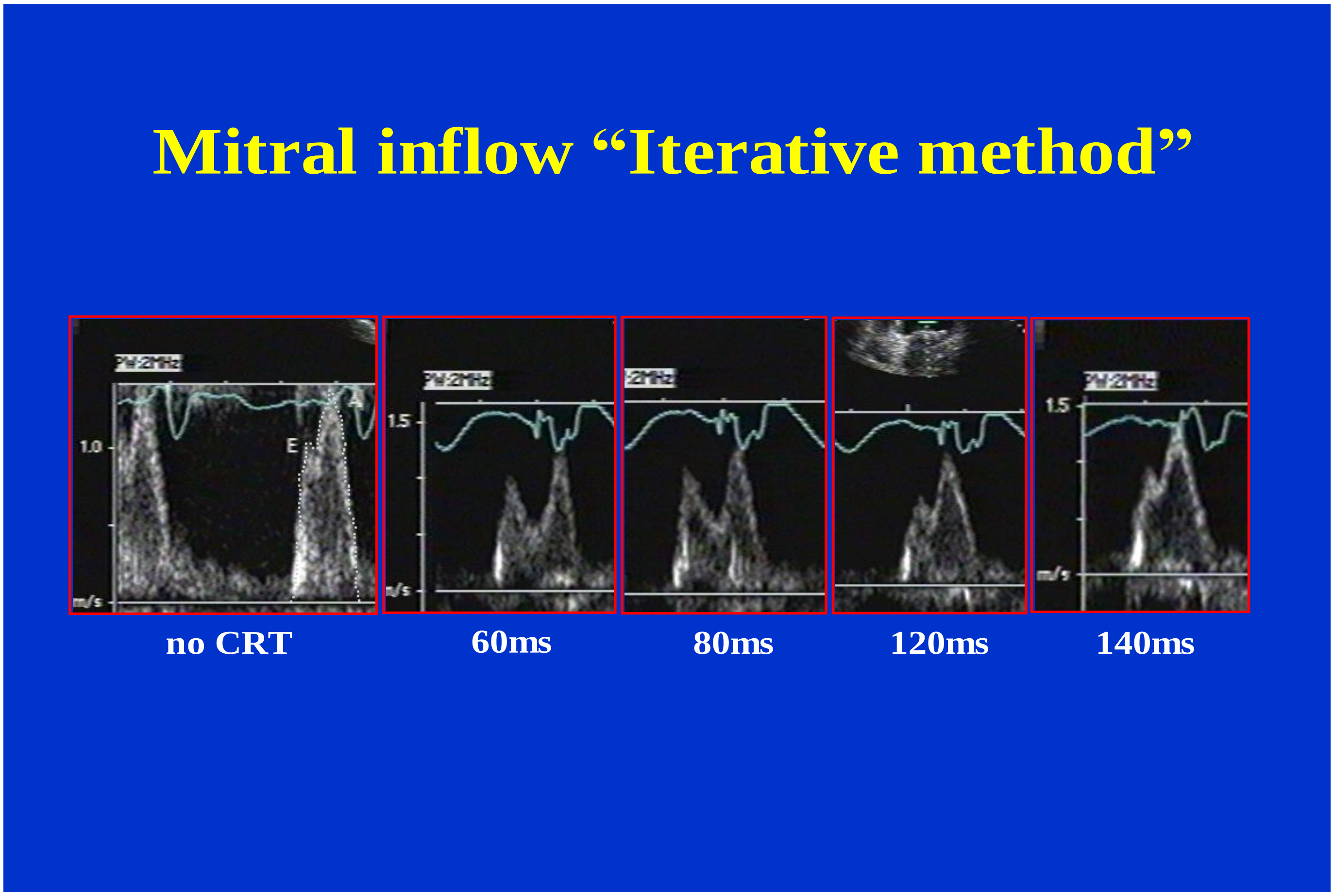
Mitral inflow: Iterative method



Programming of the CRT device at varying AVD intervals to determine the impact on LV filling by separation of the mitral E and A wave velocities.

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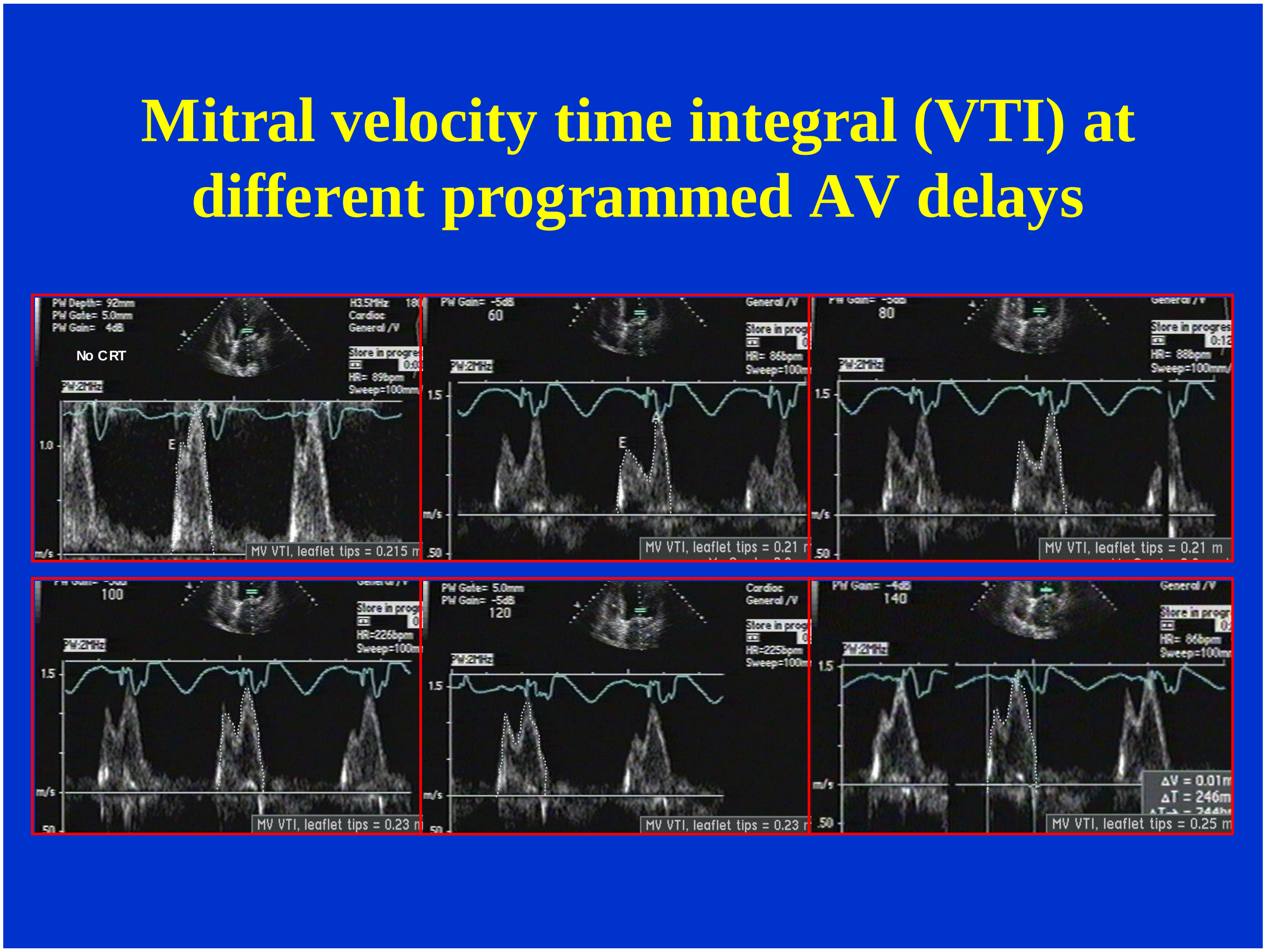
Mitral inflow: VTI method



Programming of the CRT device at varying AVD intervals to determine maximal improvement in the VTI.

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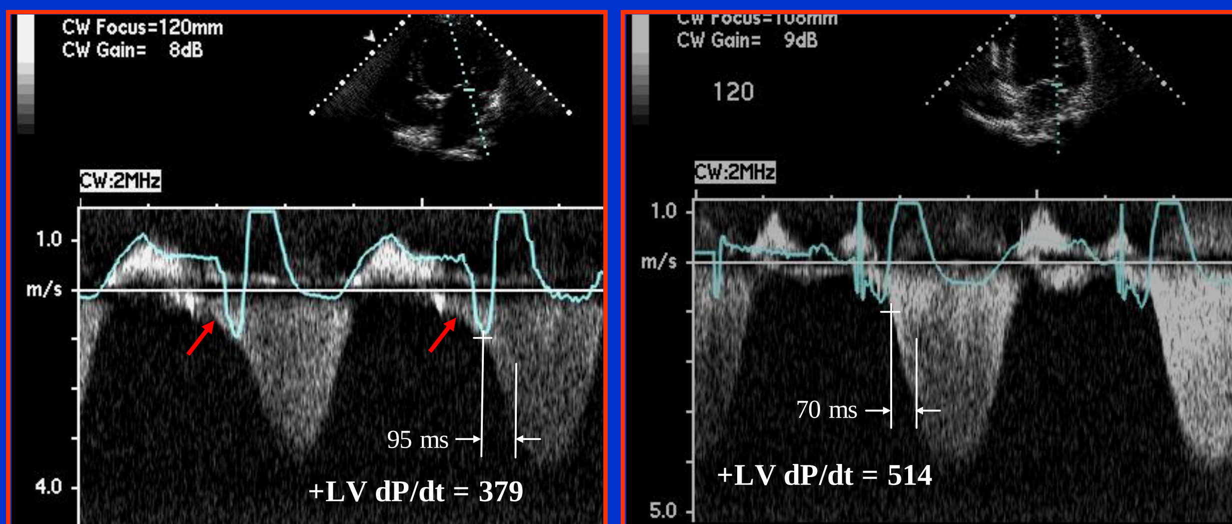
+LV dP/dt determined by the CW Doppler MR jet

CW Doppler of MR jet: (+)LV dP/dt



Pre-CRT **CRT**

Note diastolic MR (red arrow) abolished during CRT

Measurement of the +LV dP/dt, determined by CW Doppler of the MR jet velocity acceleration, prior to CRT and at an AVD of 120 ms.

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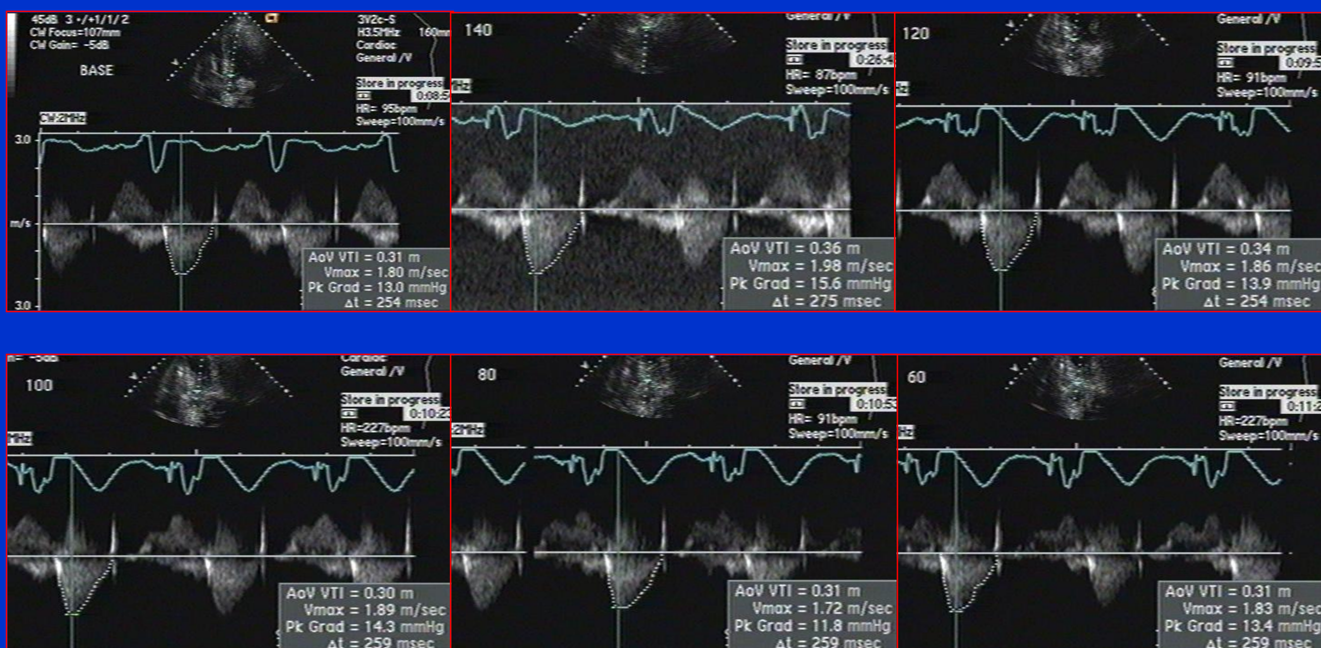
Aortic VTI method

Aortic VTI and programmed AV delays



Programming of the CRT device at varying AVD intervals to determine maximal improvement in the CW Doppler-derived aortic VTI.

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2100 Gateway Centre Blvd, Suite 310
Morrisville, NC 27560
(919)861-5574 www.asecho.org

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Conclusions: AVD Optimization by Doppler echocardiography

- Ensure there is biventricular pacing (i.e., change in QRS configuration).
- Heart rate must not vary significantly.
- Do not optimize patients with atrial fibrillation or presence of frequent dysrrhythmia (i.e., PVC or PAC).
- Obtain high quality ECG.
- Wait at least 10 cardiac cycles after changing the programmed AVD to obtain and measure time intervals.

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